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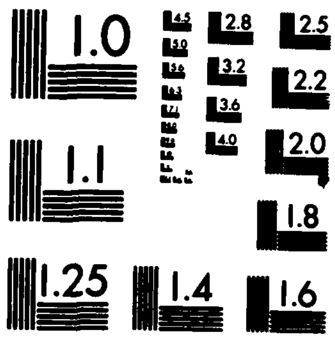
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Washington, D.C. 20591

AD-A181 622

Performance of Cracked and Seated Rigid Airport Pavements

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April 1987

Final Report

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16. Abstract

Despite the growing popularity of the crack and seat technique, little quidance is available for use in evaluating and designing overlays for cracked and seated airfield pavements. Towards solving this problem, a case study was undertaken to compare in-situ characteristics and overlay requirements of three different pavement sections at Suffolk Municipal Airport, Virginia.

Nondestructive testing ~~(NDT)~~ was used to determine the in-situ pavement properties and visual surveys were conducted to assess the condition rating of the pavements. The results of the NDT testing program were used to predict and compare the PCC layer moduli and to design AC overlays.

The results of the study indicate that: (1) while the use of the crack and seat technique appears to be effective, reflective cracking is not eliminated: (2) the strength of the PCC layer is significantly reduced after cracking and seating and hence, thicker AC overlays are required and (3) a greater degree of cracking before placing the overlay would have been helpful.

The use of a modified FAA flexible pavement procedure for the design of AC overlays is recommended as an interim procedure. NDT testing as a construction quality control device during breaking of the PCC is also recommended.

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PREFACE

This study is part of an on-going program by the Federal Aviation Administration to improve airfield pavement engineering procedures. In particular, the study focuses on a case study involving nondestructive evaluation of a cracked and seated rigid airfield pavement in Suffolk, Virginia. While this study is, in itself, insufficient to provide specific recommendations that can be implemented in future FAA advisory circulars, it is hoped this case study analysis will eventually assist the FAA in the future development of design methodologies for crack and seat pavement rehabilitation procedures.

Acknowledgement for valuable assistance on the study is given to the City of Suffolk, Virginia for access to the airport and records and to the consulting firm of Hayes, Seay, Mattern & Mattern for providing information on the original condition of the pavements at Suffolk Airport as well as design and construction records. The authors would also like to acknowledge Dr. A. McLaughlin and Mr. C. Steinhauer, of the FAA, for their assistance and valuable guidance.

PERFORMANCE OF CRACKED AND SEATED RIGID AIRPORT PAVEMENTS

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PERFORMANCE OF CRACKED AND SEATED RIGID AIRPORT PAVEMENTS

INTRODUCTION

The selection of the optimal rehabilitation strategy for implementation in airfield pavements is a very complex engineering problem that requires a logical step-by-step approach. The fundamentals of the approach are based on the necessity to: (1) determine cause of the distress(es), (2) develop a candidate list of solutions that will properly address (cure and prevent future occurrences) the problem, and (3) select the optimal rehabilitation method based upon economic and other non-monetary considerations.

For portland cement concrete (PCC) airfield pavements, the array of possible rehabilitation procedures ranges from non-overlay methods such as surface treatments, grinding and milling of the pavement, and removal and replacement of the distressed areas; to recycling of the existing pavement and/or asphaltic concrete (AC) or PCC overlays; to partial or full reconstruction of the pavement and combination of the above alternatives. In addition, many rehabilitation methods are presently under development or are being tried on an experimental basis.

Of the above referenced procedures, AC overlays are presently one of the most commonly utilized rehabilitation alternatives. They are used to strengthen the existing pavement, to restore the riding quality, and to reduce safety hazards by improving pavement surface skid resistance. However, the performance of AC overlays on PCC pavements is limited by the occurrence of reflection cracks (i.e., cracks that occur in the same place or "reflect" the locations of the underlying cracks and joints).

Reflection cracking is primarily due to the continuing thermal expansion and contraction of the concrete slabs causing horizontal movement at the joints and cracks and, to a lesser degree, vertical differential movements at cracks and joints due to traffic loadings. Also, due to the excellent bond usually achieved between a bituminous overlay and the underlying concrete, any movement in the concrete slabs is not readily absorbed along the full lengt of the overlay. Consequently, the asphaltic concrete immediately over the concrete joints and cracks can not accommodate the entire movement and a reflection crack develops.

An effective rehabilitation technique for greatly reducing the problem of reflective cracking is the Crack and

Seat (also termed Break and Seat) approach. In essence, this technique uses special slab fracturing equipment to break the slab into pieces nominally 24 to 42 inches in size. Then, a heavy proof roller is used to ensure that the slab pieces are firmly "seated" before the asphalt overlay is placed. Because the effective slab length is greatly reduced, reflective cracking is normally eliminated as a possible distress mechanism for the overlay. Cracking the pavement however, basically destroys the effective slab support of the existing PCC layer and causes it to behave like a flexible to semi-rigid system.

Despite the growing popularity of the crack and seat approach during a period when engineers are faced with unprecedented demands for innovative and economical pavement rehabilitation techniques, little guidance is available for use in evaluating and designing overlays for cracked and seated pavements. This is particularly true for airfield pavements where, unlike highway pavements, little information is available.

Fortunately, the main runway at the Suffolk Municipal Airport was recently rehabilitated betweem September, 1983 and April, 1984 using a crack and seat approach followed by an asphaltic concrete overlay. Further, the airfield taxiway and an adjacent runway were overlaid without cracking and seating and, the remainder of the airfield (primarily shoulders) was left alone (i.e., neither cracking and seating nor overlay was used on the existing PCC pavement). Thus, the Suffolk project presents a unique and excellent opportunity to develop actual field information concerning the effects of cracking and seating on the strength, overlay requirements, and performance of a specific rehabilitated airfield pavement.

STUDY OBJECTIVES

The ultimate goal of this investigation was to conduct a case study to compare the in-situ characteristics, overlay requirements and performance of three pavement sections at Suffolk Municipal Airport: one PCC pavement section which was cracked and seated and received an asphaltic concrete overlay; one PCC pavement section which was overlaid without cracking and seating, and a PCC section which was neither cracked and seated nor overlaid.

In order to accomplish this goal, three major tasks were undertaken. They are:

1. Pavement Evaluation

   In this task, non-destructive testing (NDT) was used to determine the in-situ properties of the cracked PCC material and of the uncracked PCC. Additionally, a visual condition survey of the pavements under investigation was conducted using FAA procedures outlined in FAA RD-80-55 "Procedure for Condition Survey of Civil Airports". The major objective of the visual survey was to assess the overall condition rating of the various pavements with emphasis on summarizing the amount of reflective cracking in each.

2. Material Characterization and Structural Capacity Analysis

   The NDT deflection data collected under Task 1 was analyzed, using multi-layer elastic theory, to determine the elastic modulus of the PCC layer for each NDT deflection set. The modulus results for each area were, in turn, statistically analyzed to determine an appropriate design modulus for each. Also, the design modulus value for the subgrade layer in each section was determined.

   Additionally, a comparison of the design PCC modulus value determined for each of the pavement sections was made to evaluate the strength loss in the PCC due to the cracking and seating.

   Finally, the overall composite response (i.e., structural capacity) of the various pavements was determined. In turn, the results of this analysis were used to compare the relative strengths of the pavements and the degree to which they act as rigid or flexible pavements.

3. Overlay Analysis

In this final task, the results of the material characterization and structural capacity analysis were used to design asphaltic concrete overlays on the three pavement sections assuming equivalent traffic conditions. This overlay analysis was performed using FAA procedures outlined in AC-150/5320-6C "Airport Pavement Design and Evaluation". The Asphalt Institute's Manual Series No. 11 "Full Depth Asphalt Pavements for Air Carrier Airports" was also used in the analysis.

A comparison of the differences in the overlay requirements for the three pavement sections was made. Also, the impact of these thickness requirements upon the performance of the pavements was investigated.

In summary, this report presents the results of a case study to compare the in-situ characteristics, overlay requirements, and performance of three completely different pavement sections. Unfortunately, this study by itself does not provide enough data to develop a crack/seat and AC overlay design procedure for PCC airfield pavements. However, general recommendations for developing such a procedure are made. These recommendations, in combination with other efforts such as this one, could lead to the development of an accurate methodology.

PROJECT BACKGROUND

Built in 1943, the former military airfield is currently classified as a basic transport facility serving general aviation. With three intersecting runways, Suffolk Municipal Airport is a typical example of the many military airfields built during World War II. A layout of the airfield is shown in Figure 1.

Prior to 1983, the airport had reportedly received only minor maintenance and repairs since its construction. As a consequence, the airfield pavement had deteriorated to the point that it could no longer accomodate aircraft operations safely. Several Federal and State inspections questioned the capability of the airport to accommodate aviation. The riding surface was considered too rough and the loose and spalled concrete surface was a potential source for foreign object damage to the aircraft.

As a result, the main runway (Runway 7-25) at Suffolk Municipal Airport was rehabilitated using the crack and seat with AC overlay approach between September 1983 and April 1984 in an effort to eliminate extremely rough riding and hazardous conditions. The runway is 150 feet wide but only the central 100 feet was cracked, seated and overlayed, leaving a 25 foot wide portion of the original PCC exposed on each side of the overlay. The thickness of the AC overlay ranged from 4 inches at the centerline to 1 inch at the outer edge. A more detailed description of the rehabilitation of Runway 7-25 is presented in Appendix E.

In October of 1985, approximately 1,260 feet of an adjacent runway now used exclusively as a vehicular "drag strip" was overlayed with a similar thickness (approximately 2 inches) of the identical asphalt concrete mix but without cracking and seating. In addition, the taxiway connecting the southern end of Runway 7-25 to the Fixed Base Operator and on to the intersection of Runways 7-25 and 15-33 was rehabilitated with an AC overlay (no cracking and seating) between October 1985 and June 1986.

The original pavement structure for both runways and the taxiway is 6 inches of PCC placed directly on prepared subgrade. The PCC slabs comprising Runway 7-25 are 12.5 feet wide (transversely) and 15 feet long (longitudinally). The longitudinal centerline joint is an 8 inch thickened edge expansion joint. The longitudinal construction joints have an 8 inch thickened keyed section and are evenly spaced every 25 feet with 6 inch longitudinal dummy joints located halfway (12.5 feet) between each keyed construction joint. The 6 inch dowelled transverse expansion joints are regularly spaced at 120 feet intervals with transverse construction/contraction

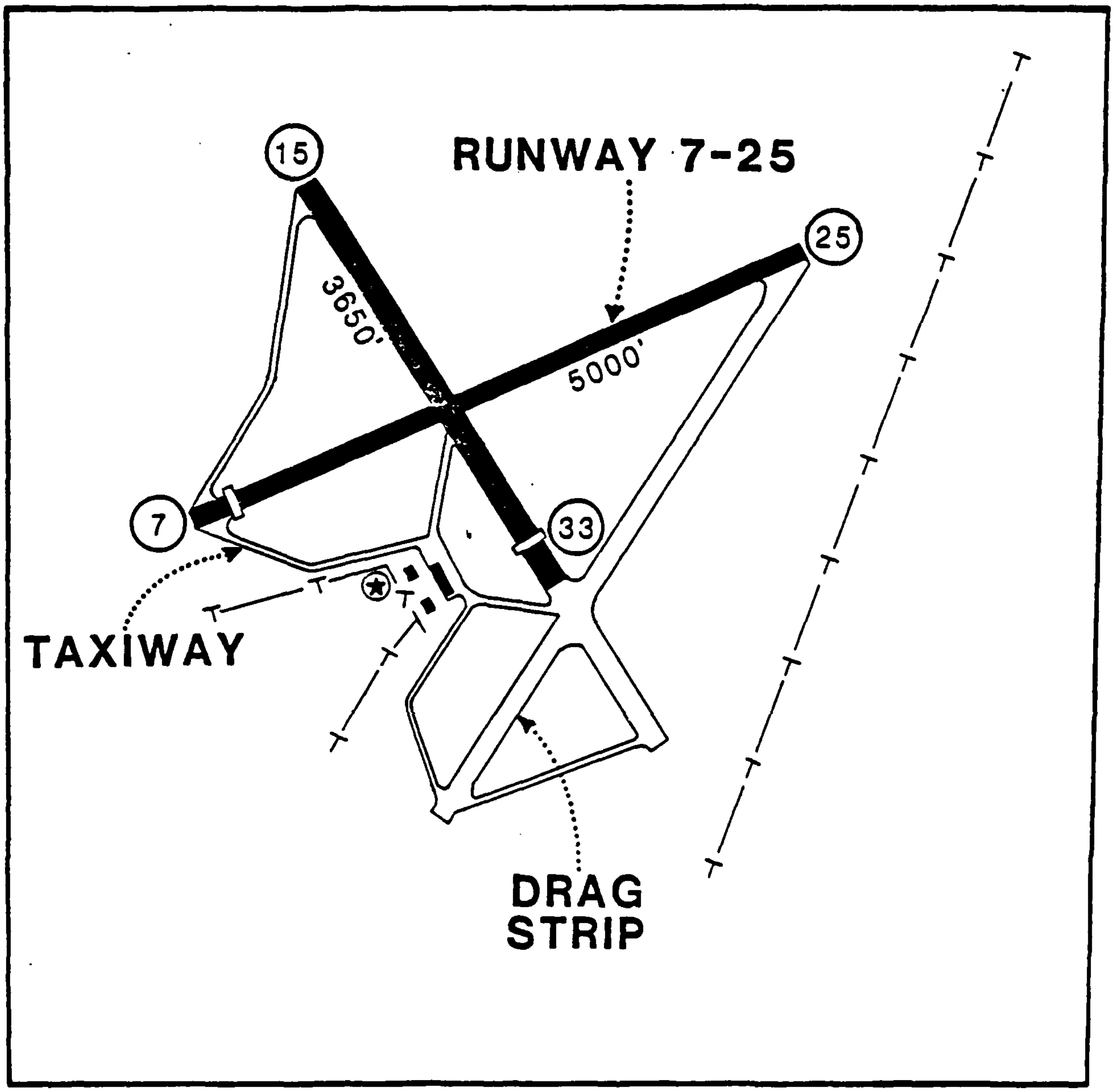


FIGURE 1. LAYOUT OF SUFFOLK MUNICIPAL AIRPORT

joints evenly spaced between the expansion joints at 15 foot intervals. There is no reinforcement in any of the PCC pavement on the airfield.

Observations of the two runway pavement sections in 1985 showed that the performance of the two was already considerably different. The uncracked section experiencing reflective cracking and the crack and seated section was performing well. This difference in performance occurred in two years.

Considering that the pavement sections under investigation have the same original pavement structure yet received very different rehabilitation measures and are performing differently, an excellent opportunity exists to conduct a comparison study of the PCC layers and to develop preliminary recommendations for characterizing cracked and seated PCC layers for design purposes. Such a study is presented and its results discussed in the ensuing sections of this report.

PAVEMENT EVALUATION

In an effort to characterize the condition and performance of the pavements at Suffolk Municipal Airport, field evaluation studies were conducted by PCS, Inc. They included a non-destructive testing (NDT) investigation and a visual condition distress survey of the three pavement sections. Both of these studies were performed on October, 1986. In addition, the results of a visual condition survey performed in 1983 (before the rehabilitation) by Hayes, Seay, Mattern & Mattern were incorporated into the overall pavement evaluation effort.

Results of the NDT testing program were used to determine the in-situ properties of the cracked PCC material and of the uncracked PCC. On the other hand, the results of the visual condition surveys were used to assess the overall condition of the pavement sections under consideration with emphasis on summarizing the amount of reflective cracking in each.

Non-Destructive Testing

Non-destructive testing of the pavements at Suffolk Municipal Airport was conducted using a Phonix ML10000 falling weight deflectometer (FWD). The Phonix ML10000 FWD is a trailer mounted pavement loading device designed to assess the load deformation characteristics of highway and airfield pavements. This device has a dynamic loading range of 2300 pounds to in excess of 23,000 pounds while maintaining an effective loading time of 20 to 40 milliseconds.

The standard electronic package of the FWD consists of five velocity transducers mounted on a raise/lower bar and a single velocity transducer mounted through the center of the loading plate which measure the load-induced deformations. Additional features of the FWD include 300 mm or 450 mm loading plate, air and pavement recording system, and a distance measuring device.

A more complete description of the FWD, the data collection process and output format is presented in Appendix A. In the ensuing paragraphs, a more detailed description of the NDT testing program at Suffolk Municipal Airport is presented.

The NDT testing of Runway 7-25 was conducted to assess the load-deformation characteristics of both the cracked, seated and overlayed PCC concrete and the un-rehabilitated PCC shoulders. The tests were conducted in the left and right wheel paths (approximately 6 to 8 feet from the centerline) at staggered intervals of 100 feet. The testing of the PCC shoulders was conducted at approximately 100 foot intervals on

the center of slabs. The shoulder testing included both sound and cracked (distressed) slabs.

The NDT of the taxiway investigated was conducted by alternating to the left and right of the centerline at approximately 100 foot intervals.

The NDT of the drag strip included the evaluation of the asphalt overlay, sound and cracked slabs adjacent to the overlay section and tests of the load transfer efficiency of selected joints. The tests conducted on the 1260 foot overlay section of the drag strip were made in the left and right "wheel paths", approximately 6 to 8 feet from the center. Tests were also conducted on random sound and cracked slabs to provide some reference data for comparison studies. Lastly, PCS conducted a limited study to assess the load transfer efficiency of the concrete joints.

A summary of the NDT testing by pavement area is presented in Table 1. In Table 2, the results of the NDT data collection effort is presented for the left wheel path of the drag strip. Figure 2 shows the same data in graphical form. Both Table 2 and Figure 2 are presented here for illustrative purposes. A complete set of the NDT field data and normalized deflection plots is presented in Appendix B.

Visual Condition Survey

A visual condition distress survey was conducted on the overlaid portion of Runway 7-25 and the drag strip. The functional condition survey was conducted to parallel the NDT structural evaluation and was performed in accordance with FAA procedures outlined in FAA RD 80-55 "Procedure for Condition Survey of Civil Airports". In addition to the analysis of the visual condition survey data collected on October, 1986 (see Appendix C), PCS, Inc. also analyzed condition survey notes made by Hayes, Seay, Mattern & Mattern (HSM&M) in 1983 prior to the rehabilitation of Runway 7-25.

The cracked, seated and overlaid portion of Runway 7-25 was subdivided into 4500 square foot units and a systematic random condition survey was conducted. A total of 37 of the 112 sample units were surveyed. The resulting pavement condition index (PCI) is 90 and the corresponding rating is EXCELLENT. The only significant distress noted was low severity joint reflection cracking. The density of the joint reflection cracking based on total area surveyed is approximately 5 percent. A complete unit by unit summary of the Runway 7-25 condition survey is presented in Tables 3 and 4. Although the joint reflection cracking is significant enough to reduce the PCI to 90 percent in only 2 years, this cracked seated and overlaid pavement is in excellent condition according to the PCI procedure; despite the poor condition of the base concrete pavement prior to

TABLE 1

SUMMARY OF NDT

PAVEMENT FEATURE	# TESTS	
RW 7-25 LEFT WHEEL PATH	50	
RW 7-25 RIGHT WHEEL PATH	50	
RW 7-25 LEFT SHOULDER	55	
RW 7-25 RIGHT SHOULDER	45	
	SUBTOTAL:	200
TAXIWAY	20	
	SUBTOTAL:	20
DRAG STRIP LEFT WHEEL PATH	37	
DRAG STRIP RIGHT WHEEL PATH	17	
DRAG STRIP SHOULDERS - SOUND SLABS	14	
DRAG STRIP SHOULDERS - CRACKED SLABS	15	
DRAG STRIP JOINTS	10	
	SUBTOTAL:	93
	TOTAL:	313

TABLE 2

EXAMPLE OF NDT DATA COLLECTED
(DRAG STRIP - LEFT WHEEL PATH)

File: E:SUFF-DSL.BSN
Project/Client Name: SUFF-FAA
Section Identification: DRAGSTRIP-LEFT

TEST POINT	SPECIAL REMARKS	STATION	TIME	D(1	D(2)	D(3)	D(4)	D(5)	D(6)	LOAD	TEMP
				DEFLECTIONS IN MILS							
	RADIAL OFFSETS IN INCHES			0.0	8.3	15.4	20.1	31.9	50.0		
1	LEFTSIDE	10.600	10:54:29	18.9	16.9	15.0	12.8	8.9	4.9	20289	79
2		11.092	10:56:31	16.3	15.5	13.5	13.7	11.4	8.0	21216	77
3		11.355	10:58:32	13.9	12.6	11.3	10.4	8.0	5.1	20083	77
4		11.584	11:00:28	16.4	14.9	13.3	12.5	9.7	6.1	20083	79
5		11.814	11:02:32	15.6	13.9	12.5	11.4	8.6	5.2	20083	77
6		12.076	11:04:26	12.7	11.1	9.9	9.3	7.2	4.7	20289	79
7		12.372	11:06:21	14.4	12.6	11.3	10.3	7.8	4.8	20289	79
8		12.667	11:08:13	14.4	12.8	11.6	10.7	8.3	5.3	20289	77
9		12.929	11:10:06	17.2	15.4	13.6	12.2	8.9	5.2	20299	77
10		13.225	11:12:18	15.2	13.5	12.1	11.1	8.3	5.0	20083	79
11		13.487	11:14:14	17.3	13.9	12.7	10.9	8.1	4.9	20289	79
12		13.315	11:16:17	14.9	12.7	12.0	10.5	8.1	5.2	20289	79
13		14.143	11:18:23	19.4	15.2	13.6	13.0	10.7	5.7	20083	77
14		14.439	11:20:19	13.7	12.2	11.3	10.1	7.6	4.6	20289	79
15		14.832	11:22:20	16.5	15.0	13.3	12.4	9.5	5.9	20083	79
16		15.226	11:24:21	16.9	15.4	13.9	12.6	9.6	4.6	20083	79
17		15.521	11:26:18	15.5	14.1	13.4	11.7	8.8	5.4	20289	79
18		15.849	11:28:18	15.8	14.4	12.9	12.0	9.1	5.6	20083	77
19		16.177	11:30:11	17.4	15.2	13.9	12.5	9.6	5.9	20083	79
20		16.506	11:32:16	16.2	13.5	12.7	11.4	8.8	5.3	20083	82
21		16.834	11:34:18	16.5	14.3	12.6	12.7	10.7	4.4	20083	79
22		17.162	11:36:23	19.3	15.6	14.7	13.1	10.4	6.8	20083	77
23		17.490	11:38:23	39.4	28.1	23.3	16.0	10.4	6.1	19877	79
24		17.818	11:40:36	15.6	13.0	11.3	11.2	9.2	6.2	20083	79
25		18.146	11:42:54	30.5	23.7	34.6	18.1	12.9	7.2	19877	79
26		18.474	11:44:56	17.1	15.3	14.2	13.0	10.2	6.3	20083	79
27	CRACKING	18.802	11:47:01	17.0	14.7	14.8	12.2	9.4	6.1	20083	79
28		19.130	11:48:55	25.4	25.0	19.3	23.9	5.2	3.9	19877	79
29	CRACKING	19.458	11:51:00	49.3	56.1	30.4	8.0	6.0	3.9	19671	79
30		19.786	11:53:05	17.7	15.4	14.7	12.7	9.7	5.9	20083	79
31		20.114	11:55:00	19.1	17.3	15.9	14.7	11.4	7.2	20083	81
32		20.672	11:57:01	29.6	28.5	19.8	12.9	8.2	5.2	20083	79
33		21.099	11:59:01	18.3	16.1	15.2	13.5	10.5	6.7	20083	77
34		21.427	12:00:53	16.8	15.2	14.0	12.7	9.8	6.3	20083	79
35	CRACKING	21.853	12:05:01	28.8	23.4	6.8	17.4	12.3	7.1	20083	79
36	SLAB	21.525	12:07:01	14.5	12.8	11.4	10.6	8.1	5.2	20083	81
37		21.853	12:09:20	17.8	16.5	15.2	13.8	10.7	6.7	20083	79

DEFLECTION DATA STATISTICS

	D(1	D(2)	D(3)	D(4)	D(5)	D(6)	LOAD
50th Percentile Values	19.2	17.1	14.7	12.6	9.2	5.6	20136
85th Percentile Values	27.0	25.2	20.0	15.5	10.9	6.6	
95th Percentile Values	31.5	29.9	23.2	17.2	11.8	7.2	

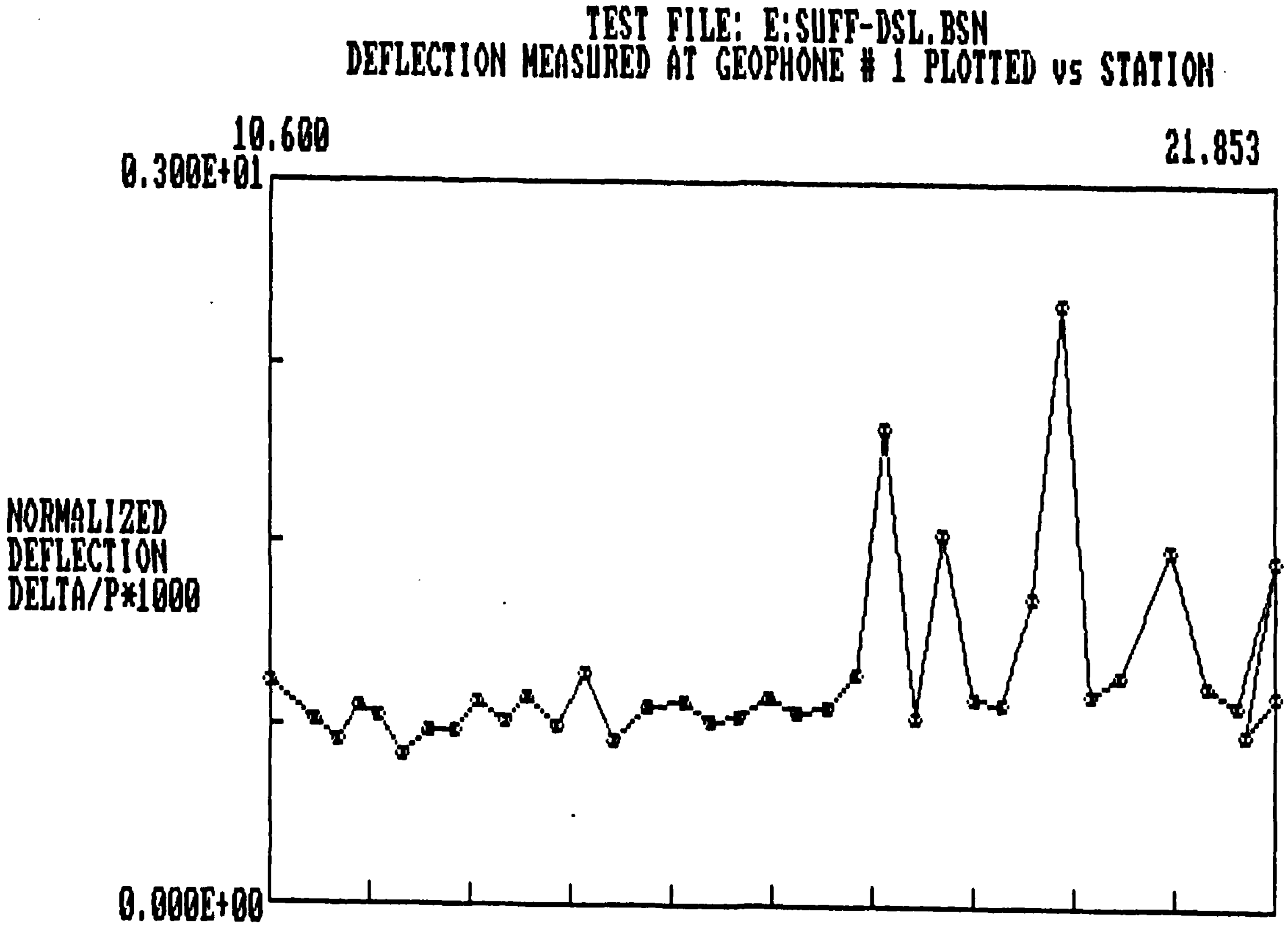


FIGURE 2. NORMALIZED DEFLECTION PLOT (DRAG STRIP - LEFT WHEEL PATH)

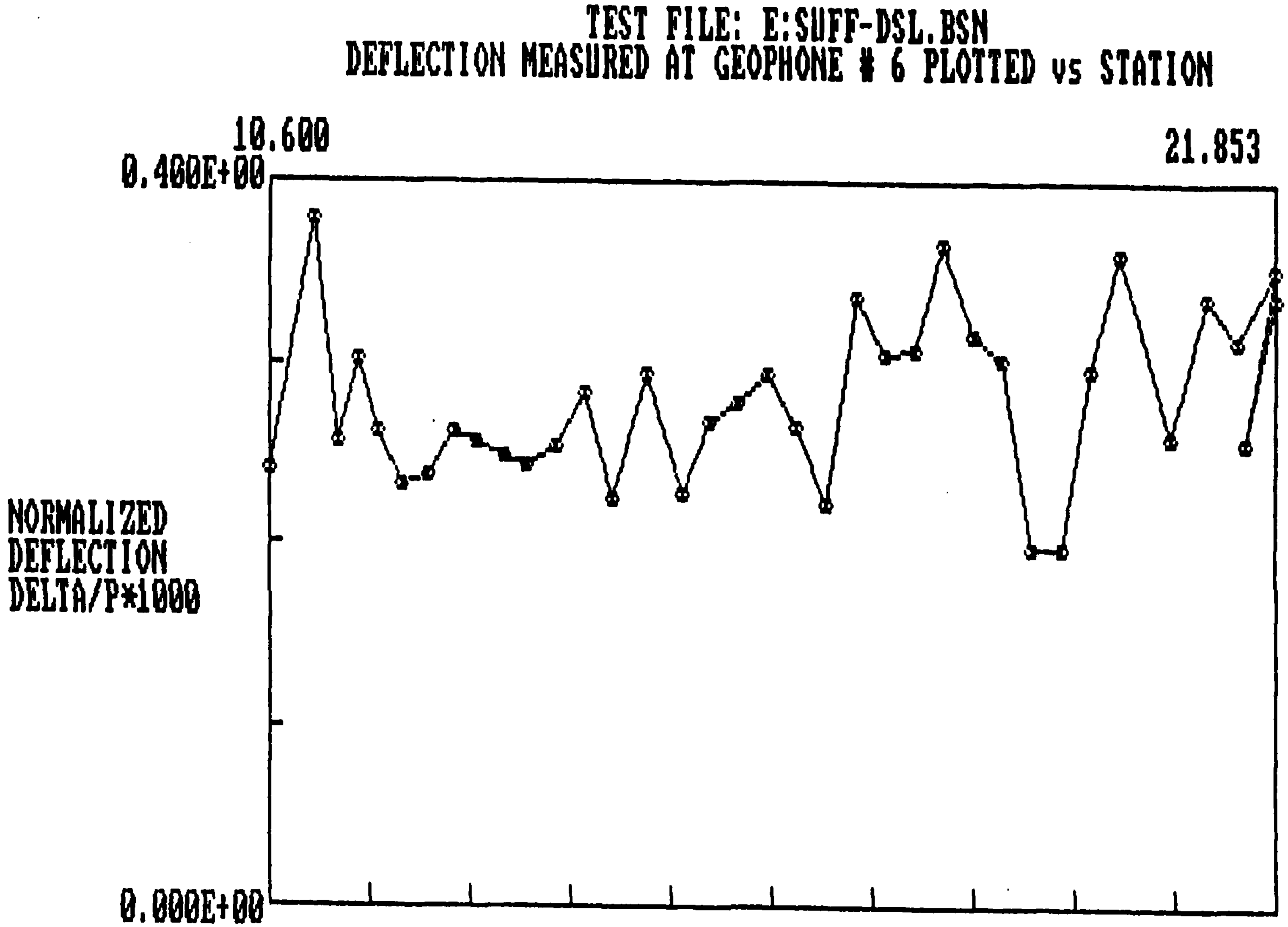


FIGURE 2. CONT'D

TABLE 3

PAVEMENT DISTRESS SURVEY RESULTS
RW 7-25 - UNIT SUMMARY - AC OVERLAY

UNIT NUMBER	UNIT AREA (SQ. FT.)	PCI (UNIT)
2	4500	84
5	4500	84
8	4500	96
11	4500	96
14	4500	93
17	4500	86
20	4500	88
24	4500	94
25	4500	88
28	4500	86
31	4500	96
34	4500	93
37	4500	89
40	4500	89
43	4500	93
46	4500	91
49	4500	82
51	4500	98
52	4500	90
55	4500	83
58	4500	90
61	4500	83
64	4500	93
67	4500	83
70	4500	91
73	4500	84
76	4500	90
79	4500	89
82	4500	96
85	4500	91
88	4500	97
91	4500	94
94	4500	90
97	4500	90
100	4500	93
103	4500	95
106	4500	90

AVERAGE PCI FOR FEATURE: 90

CONDITION RATING: EXCELLENT

AREA OF FEATURE: 500,000 S.F.

TABLE 4

PAVEMENT DISTRESS SURVEY RESULTS
RW 7-25 - DISTRESS FREQUENCY SUMMARY - AC OVERLAY

FEATURE: RW 7 – 25
AREA OF FEATURE (SQ. FT.): 500,000
NUMBER OF UNITS SAMPLED: 37
TOTAL AREA SAMPLED: 166,500
PERCENTAGE OF AREA SAMPLED: 33.3

DISTRESS DENSITY AS PERCENT OF AREA SAMPLED

FLEXIBLE DISTRESS TYPES	SEVERITY LEVEL LOW OR N/A	MEDIUM	HIGH
1. ALLIGATOR CRACKING	0	0	0
2. BLEEDING	0	0	0
3. BLOCK CRACKING	0	0	0
4. CORRUGATION	0	0	0
5. DEPRESSION	0	0	0
6. JET BLAST	0	0	0
7. JOINT REFLECTION	5.12	0	0
8. L/T CRACKING	0	0	0
9. OIL SPILLAGE	0	0	0
10. PATCHING	0	0	0
11. POLISHED AGGREGATE	0	0	0
12. RAVELING/WEATHERING	0	0	0
13. RUTTING	0	0	0
14. SHOVING FROM PCC	0	0	0
15. SLIPPAGE CRACKING	0	0	0
16. SWELL	0	0	0

rehabilitation. The effectiveness of the crack and seat program prior to the overlay placement is particularly evident in consideration of the fact that the PCI analysis of the HSM&M field notes indicated that the condition of the base PCC pavement was FAIR with a PCI of 44. Of particular importance and significance is the observation that 10.7 and 5.7 percent of the slabs exhibited low and medium severity linear/transverse/diagonal (L/T/D) cracking, respectively, prior to rehabilitation. As a result of the crack and seat program however, virtually none of these cracks have reflected through the asphalt concrete overlay. A complete summary of the Runway 7-25 base PCC pavement condition prior to rehabilitation is presented in Tables 5 and 6.

A condition survey analysis of the HSM&M field notes for the PCC shoulders of Runway 7-25 indicates that the condition of the non-trafficked areas was only slightly better than the central 100 feet. The PCIs of the West and East shoulders were 58 and 54 respectively with joint spalling, L/T/D cracking and sealing detracting the most from the pavement condition. A summary of these condition survey results are presented in Tables 7 through 10.

The visual condition distress survey of the drag strip was conducted on 100 percent of the AC overlaid pavement because of its limited size. The drag strip overlay as discussed previously, is approximately 1260 feet long by 50 feet. This overlay exhibits a higher frequency of distress as compared to Runway 7-25 despite the fact that it was placed more recently. The PCI of the drag strip is 85 and the condition rating is VERY GOOD. The percentage of joint reflection cracking is approximately 7 percent but more significantly L/T/D cracking is approximately 2 percent by total area. Tables 11 and 12 present a summary of the drag strip condition survey results. No information regarding the condition of the drag strip base PCC pavement prior to the overlay was available, however, the condition of exposed slabs on the shoulders of the overlay and the remainder of the old runway were generally poor with few slabs completely sound.

Although a detailed condition survey of the taxiway was not conducted, it was observed that 100 percent of the concrete joints had reflected through the overlay in less than 6 months.

In summary, the results of the pavement condition survey (summarized in Table 13) indicate that the crack and seat with AC overlay approach has proven effective in reducing reflective cracking. However, a fairly significant percentage of the concrete joints reflected through the Runway 7-25 overlay despite the crack and seat technique.

TABLE 5

PAVEMENT DISTRESS SURVEY RESULTS
RW 7-25 - UNIT SUMMARY - JRC PAVEMENT PRIOR TO OVERLAY

UNIT NO.	NO. OF SLABS	PCI (UNIT)
2	24	49.0
5	24	67.5
8	24	78.5
11	24	87.5
14	24	49.0
17	24	64.5
20	24	84.5
24	24	31.0
25	24	86.5
28	24	77.5
31	24	42.0
34	24	38.5
37	24	32.0
40	24	15.0
43	24	45.0
46	24	33.0
49	24	43.5
52	24	36.5
55	24	58.5
58	24	74.5
61	24	38.0
64	24	33.5
67	24	27.0
70	24	37.5
73	24	17.0
76	24	24.5
79	24	10.5
82	24	55.5
85	24	11.0
88	24	53.5
91	24	15.0
94	24	29.0
97	24	41.5
100	24	32.5
103	24	9.0
106	24	52.5

AVERAGE PCI FOR FEATURE: 43.9

CONDITION RATING: FAIR

TABLE 6

PAVEMENT DISTRESS SURVEY RESULTS
RW 7-25 - DISTRESS FREQUENCY SUMMARY
JRC PAVEMENT PRIOR TO OVERLAY

FEATURE: RW 7-25
SLABS IN FEATURE: 2464
NUMBER OF UNITS SAMPLED: 36
TOTAL SLABS SAMPLED: 864
PERCENTAGE OF SLABS SAMPLES: 35.06

DISTRESS DENSITY AS PERCENT OF SLABS SAMPLED

RIGID DISTRESS TYPES	SEVERITY LEVEL LOW OR N/A	MEDIUM	HIGH
1. BLOW-UP	0	0	0
2. CORNER BREAK	0	0	0
3. L/T/D CRACKING	10.65	5.67	1.04
4. 'D' CRACKING	0	0	0
5. JOINT SEAL DAMAGE	0	0	0
6. PATCHING < 5 SQ. FT.	0	0	0
7. PATCHING	3.47	0.58	0.23
8. POPOUTS	0	0	0
9. PUMPING	0	0	0
10. SCALING/MAP CRACKING	0.93	3.82	2.43
11. SETTLEMENT/FAULTING	6.48	2.32	0.93
12. SHATTERED SLAB	3.24	4.17	4.05
13. SHRINKAGE CRACKING	0	0	0
14. SPALLING - JOINT	2.31	10.88	3.01
15. SPALLING - CORNER	0	0	0

TABLE 7

PAVEMENT DISTRESS SURVEY RESULTS
RW 7-25 - WEST SHOULDER - UNIT SUMMARY (1983)

UNIT NO.	NO. OF SLABS	PCI (UNIT)
1	20	27.0
4	20	77.5
7	20	66.0
10	20	47.5
13	20	61.0
16	20	29.0
19	20	60.0
22	20	84.0
25	20	76.0
28	20	86.5
31	20	25.5

AVERAGE PCI FOR FEATURE: 58

CONDITION RATING: GOOD

TABLE 8

PAVEMENT DISTRESS SURVEY RESULTS
RW 7-25 - WEST SHOULDER - DISTRESS FREQUENCY SUMMARY (1983)

FEATURE: RW 7-25LS
SLABS IN FEATURE: 642
NUMBER OF UNITS SAMPLED: 11
TOTAL SLABS SAMPLED: 220
PERCENTAGE OF SLABS SAMPLED: 34.27

DISTRESS DENSITY AS PERCENT OF SLABS SAMPLED

RIGID DISTRESS TYPES	SEVERITY LEVEL LOW OR N/A	MEDIUM	HIGH
1. BLOW-UP	0	0	0
2. CORNER BREAK	0	0	0
3. L/T/D CRACKING	1.82	.45	0
4. 'D' CRACKING	0	0	0
5. JOINT SEAL DAMAGE	0	0	0
6. PATCHING < 5 SQ. FT.	0	0	0
7. PATCHING	0	.91	0
8. POPOUTS	0	0	0
9. PUMPING	0	0	0
10. SCALING/MAP CRACKING	1.82	3.18	11.82
11. SETTLEMENT/FAULTING	.91	.91	1.82
12. SHATTERED SLAB	0	0	0
13. SHRINKAGE CRACKING	0	0	0
14. SPALLING - JOINT	0	17.27	2.73
15. SPALLING - CORNER	0	0	0

TABLE 9

PAVEMENT DISTRESS SURVEY RESULTS
RW 7-25 - EAST SHOULDER - UNIT SUMMARY (1983)

UNIT NO.	NO. OF SLABS	PCI (UNIT)
1	20	39.0
4	20	56.0
7	20	46.5
10	20	61.0
13	20	31.0
16	20	46.0
19	20	47.5
22	20	84.0
25	20	33.0
28	20	73.0
31	20	84.5

AVERAGE PCI FOR FEATURE: 54

CONDITION RATING: FAIR

TABLE 10

PAVEMENT DISTRESS SURVEY RESULTS
RW 7-25 - EAST SHOULDER - DISTRESS FREQUENCY SUMMARY (1983)

FEATURE: RW 7-25RS
SLABS IN FEATURE: 642
NUMBER OF UNITS SAMPLED: 11
TOTAL SLABS SAMPLED: 220
PERCENTAGE OF SLABS SAMPLED: 34.27

	DISTRESS DENSITY AS PERCENT OF SLABS SAMPLED		
	SEVERITY LEVEL		
RIGID DISTRESS TYPES	LOW OR N/A	MEDIUM	HIGH
1. BLOW-UP	0	0	0
2. CORNER BREAK	0	0	0
3. L/T/D CRACKING	3.18	3.18	.45
4. 'D' CRACKING	0	0	0
5. JOINT SEAL DAMAGE	0	0	0
6. PATCHING < 5 SQ. FT.	0	0	0
7. PATCHING	0	1.36	.91
8. POPOUTS	0	0	0
9. PUMPING	0	0	0
10. SCALING/MAP CRACKING	1.82	7.27	3.18
11. SETTLEMENT/FAULTING	.91	.91	2.27
12. SHATTERED SLAB	0	0	0
13. SHRINKAGE CRACKING	0	0	0
14. SPALLING - JOINT	0	23.64	4.09
15. SPALLING - CORNER	0	0	0

TABLE 11

PAVEMENT DISTRESS SURVEY RESULTS
DRAGSTRIP - UNIT SUMMARY - AC OVERLAY

UNIT NUMBER	UNIT AREA (SQ. FT.)	PCI (UNIT)
1	4800	76
2	4550	76
3	5000	85
4	5000	84
5	5000	85
6	5000	84
7	5000	87
8	5000	91
9	5000	89
10	5000	89
11	5000	87
12	5000	89
13	3750	87

AVERAGE PCI FOR FEATURE: 85

CONDITION RATING: VERY GOOD

TABLE 12

PAVEMENT DISTRESS SURVEY RESULTS
DRAGSTRIP - DISTRESS FREQUENCY SUMMARY (1986)

ASPHALT SURFACED PAVEMENT CONDITION SURVEY/DAMAGE SUMMARY

FEATURE: DRAGSTRIP
AREA OF FEATURE (SQ. FT.): 63100
NUMBER OF UNITS SAMPLED: 13
TOTAL AREA SAMPLED: 63100
PERCENTAGE OF AREA SAMPLED: 100

DISTRESS DENSITY AS PERCENT OF AREA SAMPLED

	SEVERITY LEVEL		
FLEXIBLE DISTRESSS TYPES	LOW OR N/A	MEDIUM	HIGH
1. ALLIGATOR CRACKING	0	0	0
2. BLEEDING	0	0	0
3. BLOCK CRACKING	0	0	0
4. CORRUGATION	0	0	0
5. DEPRESSION	0	0	0
6. JET BLAST	0	0	0
7. JOINT REFLECTION	6.89	0	.3
8. L/T CRACKING	2.16	0	0
9. OIL SPILLAGE	0	0	0
10. PATCHING	0	0	0
11. POLISHED AGGREGATE	0	0	0
12. RAVELING/WEATHERING	0	0	0
13. RUTTING	0	0	0
14. SHOVING FROM PCC	0	0	0
15. SLIPPAGE CRACKING	0	0	0
16. SWELL	0	0	0

TABLE 13

SUMMARY OF PCI VALUES

SECTION	CONSTRUCTION TYPE	PCI VALUE DATE: 1983	1986
Runway 7-25 (Wheel Path)	Crack/Seated PCC with AC Overlays	43.9	90.0
Runway 7-25 Left Shoulder	Original PCC (no cracking and seating or AC Overlay	58.0	
Runway 7-25 Right Shoulder	Original PCC (no cracking and seating or AC Overlay)	54.0	
Dragstrip (Wheel Path)	Original PCC with AC Overlay		85.0

MATERIAL CHARACTERIZATION AND STRUCTURAL CAPACITY ANALYSIS

The primary purpose of the material characterization study was to determine the in-situ layer elastic moduli of the pavement system based on deflection basin data collected in the field.

In order to accomplish this objective, the results of the NDT test program were used as input into the PCS EMOD computer program to determine the modulus of elasticity (Ei) for the various pavement layers. The analysis technique utilized by EMOD is based upon the concepts of linear multi-layer elastic theory and uses the Chevron N Layer computer code as a subroutine within the back calculation procedure. In general, layer moduli are estimated from the combination of E1, E2, E3 values (if 3 layers) that result in the minimum cumulative residual error at all deflection (geophone) readings. In order to utilize this program (2 and 3 layer), it is necessary to combine the actual pavement cross section into a maximum of three layers, layer thicknesses must be known or assumed and the Poisson's Ratio of each layer must be known or assumed.

Depending upon the type of analysis being conducted (i.e., rigid or flexible pavement systems), the estimated layer elastic moduli can then be correlated to other more empirical parameters such as: CBR or k. The specific correlations used in this study are described later in the section.

Layer Moduli Estimation

PCS EMOD program runs were conducted for each deflection basin test point (a total of 302) to estimate the elastic moduli of the individual layers.

Because five of the pavement areas tested had a variable thickness AC overlay and the tests were performed at different times (hence different pavement temperature), a limited sensitivity study of the influence of the AC overlay thickness (hAC) and modulus (EAC) was undertaken. The results of this study are graphically summarized in Figures 3 through 5. As expected, the predicted PCC modulus (EPCC) value increases as hAC and EAC decrease.

Using the results of the sensitivity study and the AC overlay thickness information available, the final pavement cross sections for input into the EMOD program were developed. These cross sections are presented in Figure 6. As shown in this figure, average AC overlay thicknesses of 2.75, 2 and 1.5 inches were assumed for the Runway 7-25, drag strip and taxiway, respectively.

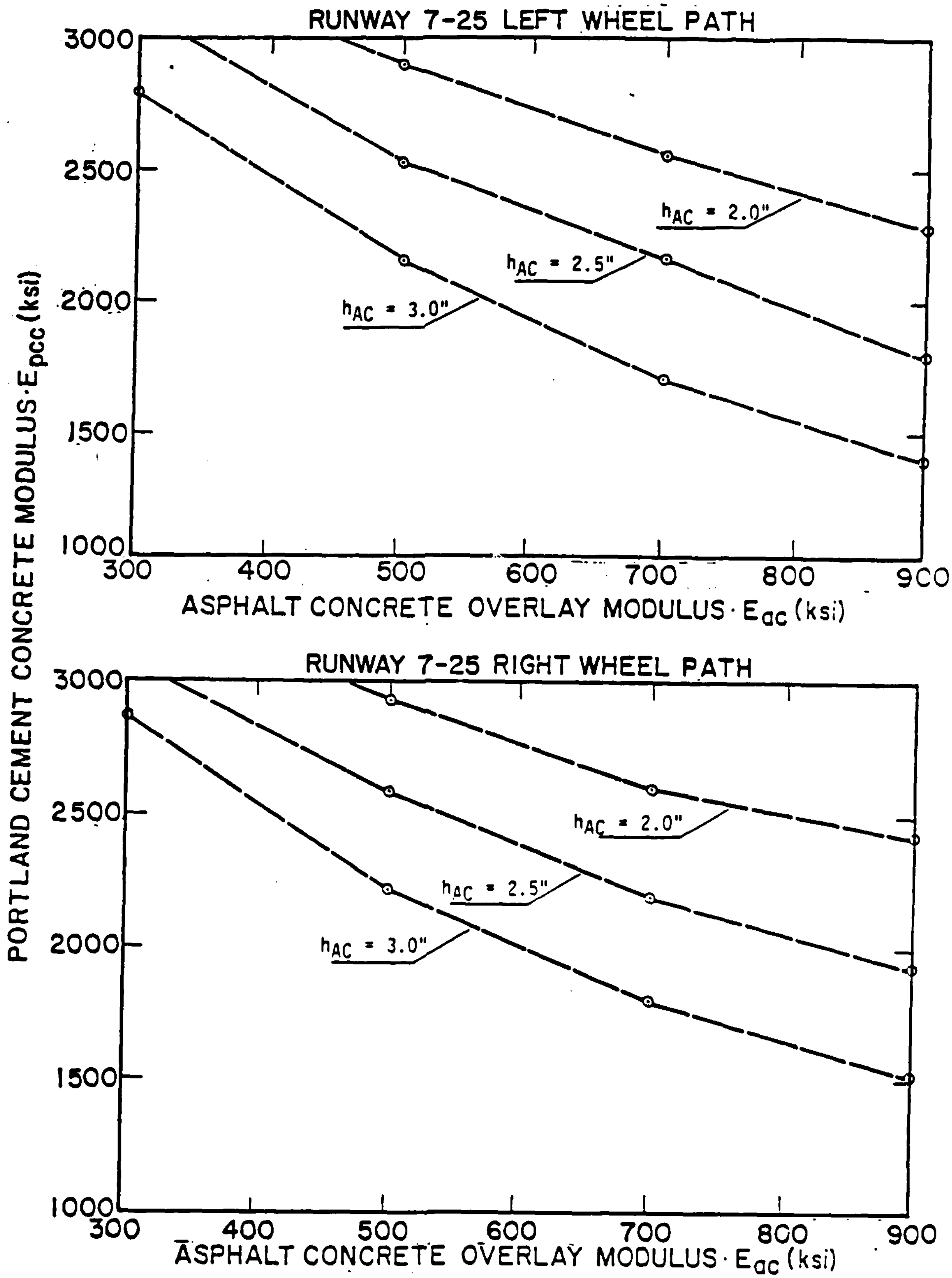


FIGURE 3. PREDICTED PCC MODULUS AS A FUNCTION OF ASSUMED AC OVERLAY THICKNESS AND ELASTIC MODULUS RUNWAY 7-25 OVERLAY

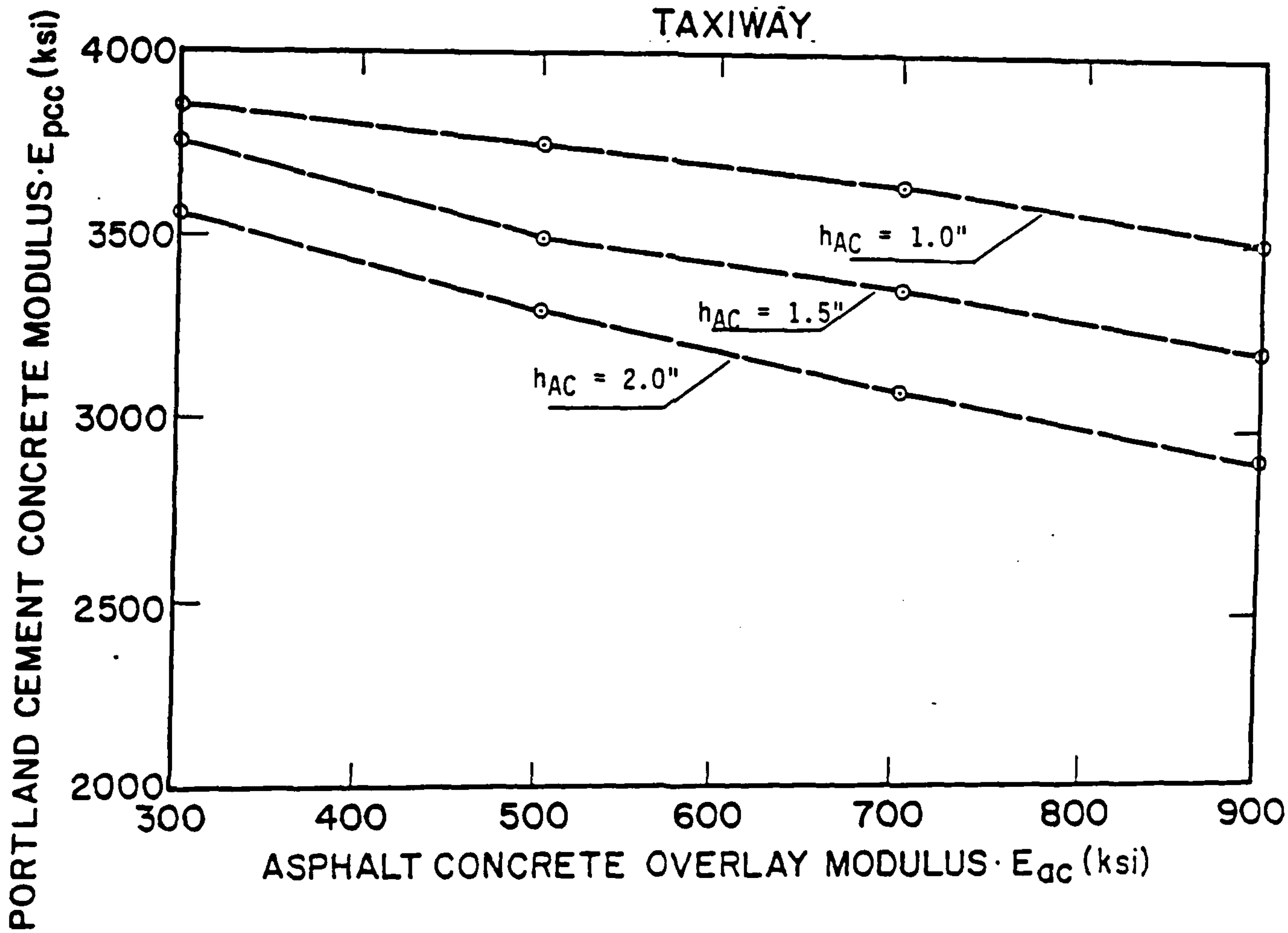


FIGURE 4. PREDICTED PCC MODULUS AS A FUNCTION OF ASSUMED AC OVERLAY THICKNESS AND ELASTIC MODULUS TAXIWAY OVERLAY

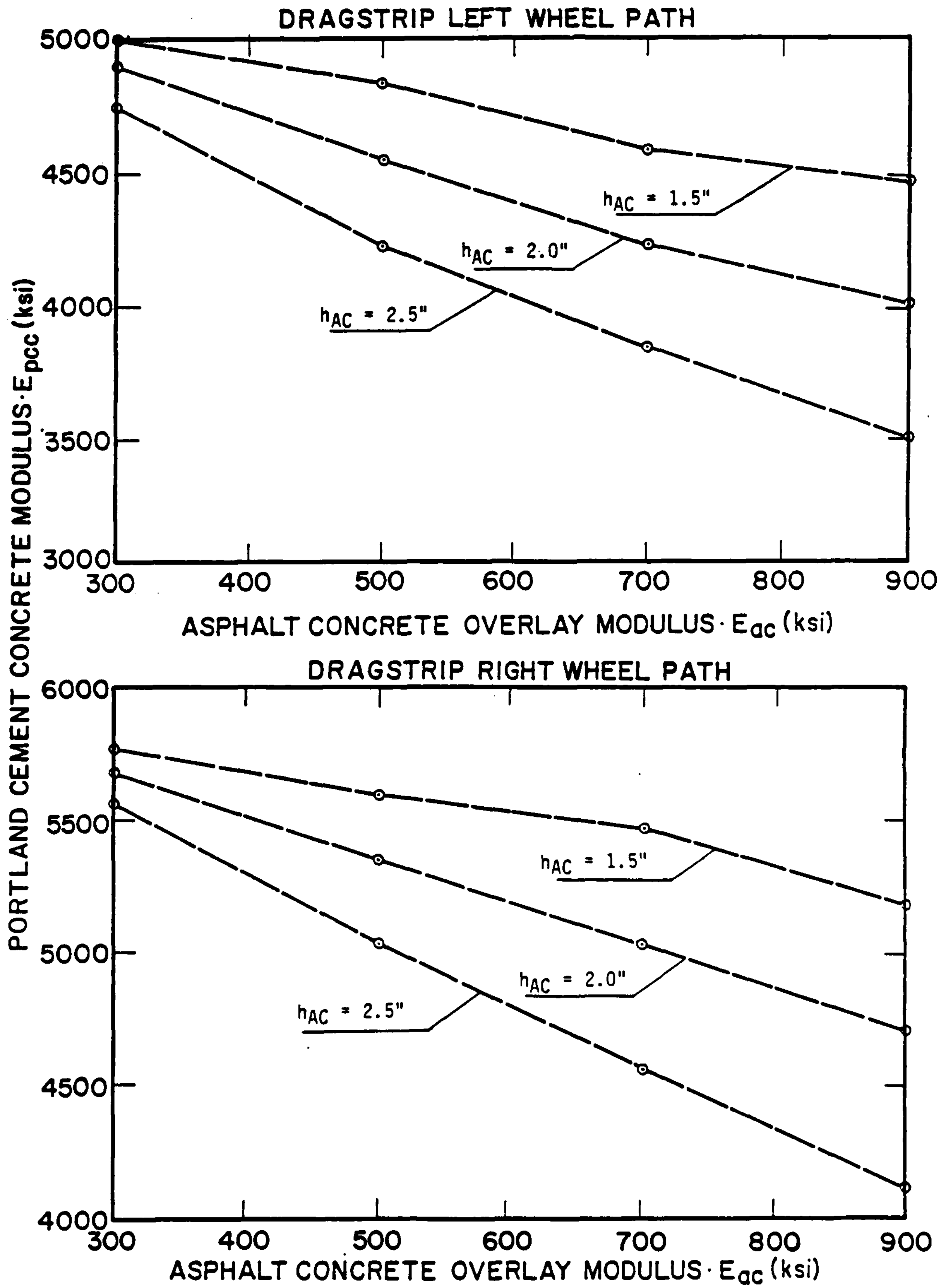


FIGURE 5. PREDICTED PCC MODULUS AS A FUNCTION OF ASSUMED AC OVERLAY THICKNESS AND ELASTIC MODULUS DRAGSTRIP OVERLAY

a. Runway 7-25, Wheel Paths (Left and Right)

AC Overlay, h_{AC} = 2.75 inches; u = 0.35

PCC; h_{PCC} = 6 inches; u = 0.15

Subgrade; h_{SG} = semi-infinite; u = 0.35

b. Drag Strip, Wheel Paths (Left and Right)

AC Overlay; h_{AC} = 2 inches; u = 0.35

PCC; h_{PCC} = 6 inches; u = 0.15

Subgrade; h_{SG} = semi-infinite; u = 0.35

c. Taxiway

AC Overlay; h_{AC} = 1.5 inches; u = 0.35

PCC; h_{PCC} = 6 inches; u = 0.15

Subgrade; h_{SG} = semi-infinite; u = 0.35

d. Runway 7-25 and Drag Strip Shoulders

PCC; h_{PCC} = 6 inches; u = 0.35

Subgrade; h_{SG} = semi-finite; u = 0.35

Figure 6. FINAL PAVEMENT CROSS SECTIONS

In addition, the elastic moduli of the asphaltic concrete overlays were fixed (i.e., constant value used) in the EMOD program runs. These EAC values were calculated using known AC mix parameters as input into The Asphalt Institute's predictive equation presented in Table 14. The predicted asphaltic concrete overlay moduli are summarized in Table 15. Because the mix properties were exactly the same for the various overlaid pavements, differences in the EAC values shown in Table 15 are due to differences in the pavement temperature. As can be seen in this table, the asphalt modulus increases as the pavement temperature decreases.

Ultimately, the pavement cross sections shown in Figure 6 and the AC overlay moduli presented in Table 15 were used in the EMOD computer analysis of the NDT measured deflection basins to estimate the in-situ layer moduli of each pavement. Appendix D summarizes the results of this computer analysis. In Table 16, a statistical summary of the predicted layer moduli is presented. And, in Table 17, a statistical summary of layer moduli is presented according to construction type.

Comparison of PCC Moduli

It was noted earlier that the crack and seat approach is an effective rehabilitation technique for greatly reducing the problem of reflective cracking. Cracking the pavement however, basically destroys the effective slab support of the existing PCC layer and causes it to behave like a flexible to semi-rigid system. Because of this, one of the major objectives of this investigations was to look at the strength loss in the PCC due to the cracking and seating.

In order to accomplish this objective, a comparison of the PCC moduli determined for each of the pavement types under investigation was made. The predicted PCC, as well as subgrade, moduli are summarized in Table 17.

As can be seen in this table, PCC moduli range from a low of 1920 ksi for the cracked, seated and overlaid pavement section to a high of 4380 ksi for the uncracked but overlaid pavements (i.e., taxiway and drag strip). For the uncracked pavements without an overlay (i.e., shoulders), the predicted modulus is EPCC = 3440 ksi. This value, while lower than that of the uncracked but overlaid pavement, is still significantly higher than that of the cracked and seated PCC.

Therefore, one can conclude that the strength of the cracked and seated pavement was significantly reduced. Quantitatively, the loss of PCC strength can be represented by a reduction in the modulus value of 56 and 44 percent when compared to the uncracked sections. These moduli reductions however, do not take into account the fact that the uncracked PCC layers are already significantly deteriorated. Thus, one can alsoconclude that the reduction in the EPCC value is even

TABLE 14

TAI-AC MODULUS PREDICTIVE EQUATION

$$\log |E^*| = 5.553833 + 0.028829\left(\frac{P_{200}}{f^{0.17033}}\right) - 0.03476\,(V_v)$$

$$+ 0.070377\,(\eta_{70^\circ F,\,10^6}) + 0.000005\left[t_p^{(1.3+0.49825\log f)}\;P_{ac}^{0.5}\right] \quad (5)$$

$$- 0.00189\left[t_p^{(1.3+0.49825\log f)}\;\frac{P_{ac}^{0.5}}{f^{1.1}}\right] + 0.931757\left(\frac{1}{f^{0.02774}}\right)$$

where

$|E^*|$ = dynamic modulus (stiffness) of asphalt concrete, psi (kPa/6.8948)

P_{200} = percent aggregate passing No. 200 sieve

f = frequency, Hz

V_v = percent air voids

$\eta_{70^\circ F,10^6}$ = absolute viscosity at $70^\circ F$, poises x 10^6

P_{ac} = asphalt content, percent by weight of mix

t_p = temperature, $^\circ F$ ($1.8^\circ C + 32$)

If sufficient viscosity data are not available to estimate $\eta_{70^\circ F,\,10^6}$, then the following relationship may be used:

$$\eta_{70^\circ F,\,10^6} = 29508.2\;\mathrm{pen}_{77^\circ F}^{-2.1939}$$

MIX TYPE

Bituminous Surface Course: Modified Virginia State Highway Type S-5

P_{200} = 2 to 6%

V_v = 4.5%

P_{ac} = 5.6 to 6.4%

$\eta_{70^\circ F,10^6}$ = 2.5 (AC-20)

f = 10 Hz

TABLE 15

PREDICTED ASPHALTIC CONCRETE OVERLAY MODULUS - lE*l

SECTION	TEMPERATURE (°F)	l E*l (Ksi)
Runway 7-25 Left Wheel Path	59	1100.0
Runway 7-25 Right Wheel Path	79	485.0
Taxiway	66	850.0
Dragstrip Left Wheel Path	79	485.0
Dragstrip Right Wheel Path	77	530.0

TABLE 16
STATISTICAL SUMMARY OF LAYER MODULI

Construction Type	Section	AC Overlay Thick. (in.)	PCC Thick. (in.)	Statistic of Interest	Layer Moduli (ksi)		
					AC Overlay	PCC	Subgrade
AC Overlay/ Cracked PCC Slab	Runway 7-25 Left Wheel Path	2.75	6.00	Mean	1100.0	1360.0	14.5
				Std. Dev.	0.0	639.2	2.0
	Runway 7-25 Right Wheel Path	2.75	6.00	Mean	485.0	2470.0	14.0
				Std. Dev.	0.0	1299.0	2.3
AC Overlay/ Uncracked PCC Slab	Taxiway	1.50	6.00	Mean	850.0	3250.0	14.2
				Std. Dev.	0.0	1990.0	5.5
	Drag Strip Left Wheel Path	2.00	6.00	Mean	485.0	4567.6	17.4
				Std. Dev.	0.0	1586.0	3.1
	Drag Strip Right Wheel Path	2.00	6.00	Mean	530.0	5294.1	17.3
				Std. Dev.	0.0	638.8	2.4
No AC Overlay/ Uncracked PCC Slab	Runway 7-25 Left Shoulder	--	6.00	Mean	--	3269.1	12.3
				Std. Dev.	--	1473.0	1.8
	Runway 7-25 Right Shoulder	--	6.00	Mean	--	3520.0	12.7
				Std. Dev.	--	1351.0	2.8
	Drag Strip Sound Slabs	--	6.00	Mean	--	4471.4	17.4
				Std. Dev.	--	854.3	3.6
	Drag Strip Cracked Slabs	--	6.0	Mean	--	2560.0	17.7
				Std. Dev.	--	1797.0	3.6

TABLE 17

STATISTICAL SUMMARY OF PCC AND SUBGRADE LAYER MODULI
ACCORDING TO CONSTRUCTION TYPE

Construction Type	Number of Test Points	Statistic of Interest	Modulus (ksi)	
			PCC Layer	Subgrade
1. Cracked/Seated PCC (with AC overlay)	100	Mean	1920	14.20
		Std. Dev.	1160	2.16
2. Uncracked PCC				
a. With AC overlay	74	Mean	4380	16.50
		Std. Dev.	1710	3.98
b. Without overlay	128	Mean	3440	13.70
		Std. Dev.	1450	3.14
c. All	202	Mean	3780	14.70
		Std. Dev.	1610	3.71
3. All	302	Mean	3160	14.60
		Std. Dev.	1720	3.28

greater if compared to that of a sound slab. The reduction in structural capacity of the cracked and seated pavement is discussed in the ensuing section.

It should also be noted that for PCC highway pavements, the new "AASHTO Guide for Design of Pavement Structures" recommends that the elastic modulus for the cracked PCC be about 500 to 1,000 ksi. In this study, the average modulus of the cracked PCC was calculated to be 1,920 ksi. Because this value is higher than the recommended range of moduli, it implies that a greater degree of cracking before the overlay would have been helpful. This may also explain why the AC overlay is showing a significant amount of cracking after only 2 to 3 years despite the crack and seat technique.

The above observations also suggest that perhaps NDT testing should be used as a construction quality control device during breaking to insure that a minimum elastic modulus is achieved before placing the AC overlay. It is important to note however, that a significant research effort to assess the influence of such factors as slab size, crack spacing and subgrade support upon the NDT derived PCC modulus value needs to be undertaken before NDT testing can be implemented as a quality control device.

The difference in moduli for the uncracked pavement sections can, in all likelihood, be attributed to the presence (taxiway and drag strip) or lack (shoulders) of an AC overlay as well as the subgrade support conditions. The average modulus of the uncracked pavements with an overlay, as expected, is 27% higher than that of the pavements without an overlay. The difference in the structural capacity of the two pavements is also discussed in the ensuing section.

Because most of the comparison up to this point has been subjective in nature, a statistical comparison of the PCC moduli was undertaken. The acceptance criteria used to determine whether or not the hypothesis that the PCC moduli are equal for the various pavement sections is shown in Table 18. The statistical test assumes that the EPCC values for each section are normally distributed and that the true standard deviations are unknown and unequal.

Using the equations shown in Table 18, the degrees of freedom (V2) and the test statistic (t1) were calculated. The resulting values are summarized in Table 19. Next, assuming "α" values of 0.05, 0.005 and 0.0005 (or confidence levels of 95, 99, and 99.9 percent, respectively) and using a two-sided confidence test yielded the $t\ \alpha/2$, V2 values shown in Table 19.

Because the $t\ \alpha/2$, V2 values (Table 19) are, in all cases, less than the t1 statistics (Table 19), the hypothesis that the pavement sections have equal means is rejected. In other

TABLE 18

HYPOTHESIS TEST OF MEANS (NORMALLY DISTRIBUTED)

Acceptance Criteria for Given Hypothesi (H: $u_x = u_y$; σ is unknown and unequal)

$$- t_{\alpha/2,\ V_2} \leq t_1 \leq + t_{\alpha/2,\ V_2}$$

where:

$$V_2 = \frac{[(S_x^2 / n_x) + (S_y^2 / n_y)]^2}{[(S_x^2 / n_x)^2 / (n_x + 1)] + [(S_y^2 / n_y)^2 / (n_y + 1)]} - 2$$

$$t_1 = \frac{(\bar{x} - \bar{y})}{\sqrt{(S_x^2 / n_x) + (S_y^2 / n_y)}}$$

where:

$\bar{x}$, $\bar{y}$ = mean of population x and y

S_x, S_y = standard deviation associated with population x and y

n_x, n_y = number of units in population x and y

V_2 = degrees of freedom (associated with hypothesis criteria)

t_1 = test statistic (t distribution)

$1 - \alpha$ = confidence level

α = "Type 1" or " error"

TABLE 19

HYPOTHESIS TEST OF MEAN PCC MODULUS VALUES

Degrees of Freedom, V_2

Construction Type

		1	2a	2b	2c
Construction Type	1	------	122	228	263
	2a	122	------	135	------
	2b	228	135	------	------
	2c	263	------	------	------

Test Statistic, t_1*

Construction Type

		1	2a	2b	2c
Construction Type	1	------	10.688	8.793	11.472
	2a	10.688	------	3.974	------
	2b	8.793	3.974	------	------
	2c	11.472	------	------	------

Construction Type:
1 = Cracked/Seated PCC
2a = Uncracked with AC Overlay
2b = Uncracked without Overlay
2c = All Uncracked

*Absolute Values

"$t_{\alpha/2}$, V_2" Values

	" α " Values		
ν	0.05	0.005	0.0005
100	1.660	2.626	3.389
200	1.653	2.601	3.339
500	1.648	2.586	3.310
∞	1.645	2.576	3.291

words, from a statistical point of view, one can conclude that the mean PCC modulus values are not the same for the pavements under investigation.

While most of the discussion in this section has focused on the comparison of PCC moduli, the effects of material variability (associated with both the PCC layer and the subgrade) upon the performance of the pavements should not be neglected. The most common measure of this variability is the standard deviation. Other parameters used as indicators of variability include the variance and coefficient of variation. Standard deviations for the pavement layer moduli at Suffolk Municipal Airport are presented in Tables 16 and 17 and Appendix D; coefficients of variation for the same pavements are included in Appendix D.

These measures of variability are generally incorporated into analysis or design procedures through the use of probability and statistics concepts. In most cases, the mean and standard deviation are used to calculate a "design" value for a specified level of reliability (or confidence). For example, if the mean subgrade modulus is selected for design purposes, there is a 50 percent probability that the pavement section will perform better (i.e., over-designed) and a 50 percent probability that the pavement will not perform as desired (i.e., under-designed). On the other hand, if the value selected for design is equal to the mean minus two standard deviations, approximately 98 percent of the pavement section will be over-designed and only 2 percent will be under-designed. Ultimately, the reliability level selected will depend on such factors as the importance of the pavement under consideration, type of traffic operating on the pavement and traffic volume; the 80 to 95 percentile value is commonly used.

In this research study, instead of a single value, a range of subgrade moduli was used in the overlay analysis. The mean PCC moduli were used in both the structural capacity analysis and the overlay design.

Structural Capacity of Pavements

While the layer moduli predicted in this study are of major importance, many of the initial construction and overlay design procedures (such as the FAA's airfield and AASHTO's highway flexible and rigid pavement design procedures) currently being used are based on the concept of equivalent AC or PCC thicknesses or empirical values which can be directly correlated to these thicknesses. They can be viewed as a representation of the load carrying capabilities of the pavement and, in most cases, are calculated based on a specific set of subgrade, traffic and environmental conditions.

In view of the above, a study was undertaken to assess the overall composite response of the pavement sections under investigation. Both equivalent AC and PCC thicknesses were determined for each pavement. In addition, a comparison of the resulting equivalent thickness values was made according to the pavement construction type.

The approach used to calculate the equivalent AC and PCC thickness of the pavements at Suffolk Municipal Airport is based on the concept of transformed sections for multi-layer elastic pavement structures.

The principles of transformation for multi-layer pavement systems are shown in Figure 7. The actual pavement structure is shown to be modeled by a series of finite thickness layers having linear elastic properties of "E" (modulus) and "u" (Poisson's Ratio) over a semi-infinite subgrade. When an external load is applied to the surface, the state of stress, strain or displacement is usually required at a user defined computational point (e.g., point "a") somewhere in the elastic layered mass. For multi-layered systems, the closed form analytical (mechanistic) solutions become mathematically more complex as the number of layers increases.

However, the complexity of the solution is greatly diminished by "transforming" the pavement layers into an equivalent transformed thickness of Z = he of material having standard elastic properties of "Es" and "us". By transforming the upper layers (of modulus E1, E2, etc...) into a layer of "Es, us" material, the stress-strain-displacement solutions are now for a two layer elastic system (Burmister's Two-layer Solution).

Thus, in Figure 7, states of stress (strain, displacement) found at Z = he, r = r1, under the two layer condition yield the same states of stress as the computational point defined by Z = h1 + h2; r = r1, within the multi-layer system.

The transformed thickness, Z = he is found from:

$$h_e = f \sum_{i=1}^{n-1} h_i \left(\frac{E_i \, (1 - u_s)^2}{E_s \, (1 - u_i)^2} \right)^{1/3}$$

The value of "f" is approximately equivalent to f = 0.9 (0.8 < f < 1.0), with f = 0.90 for a 2 layered system and f = 1.0 for the first layer of a multi-layered system.

Using the equation presented above, the pavements at Suffolk Municipal Airport were first converted into equivalent AC thicknesses having a modulus of Es = 930 ksi. This Es value represents the temperature corrected value (70o F) of an asphaltic concrete mixture having the same mix properties as

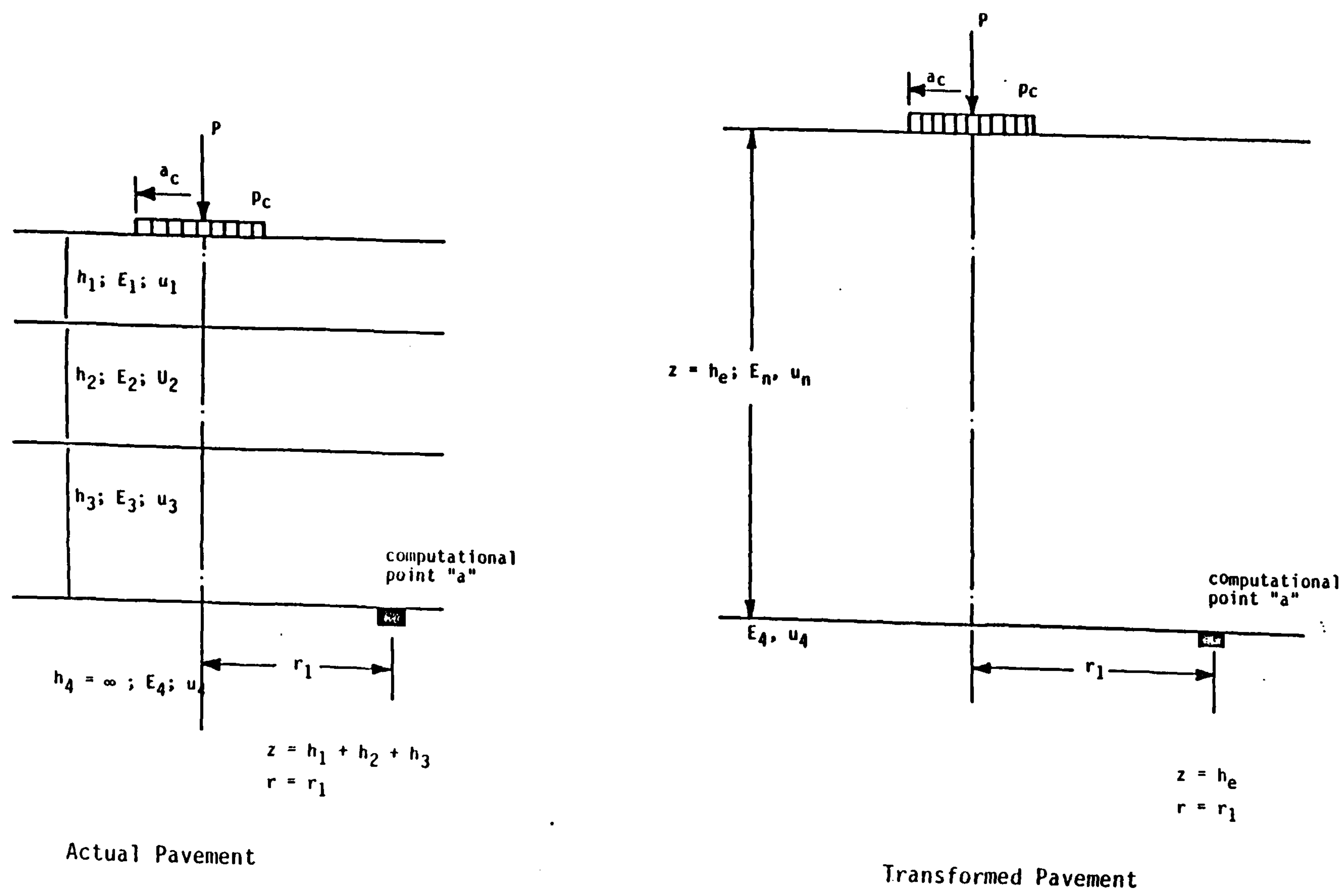


FIGURE 7 PRINCIPLE OF TRANSFORMED SECTION ANALYSIS

those used in the overlays (see Table 14). The resulting equivalent thicknesses are summarized in Table 20.

Next, the same pavements were converted into equivalent PCC thicknesses having a modulus of Es = 5000 ksi. This Es value was assumed to be representative of high quality, sound PCC. The resulting thicknesses are presented in Table 21.

Structural Capacity Comparison

Based upon the information presented in Tables 20 and 21, the following observations were made:

- The equivalent thickness (both AC and PCC) of the cracked and seated PCC is significantly lower than that of the uncracked sections. The reduction in equivalent thickness, due to cracking and seating of the PCC, is approximately 18 to 25 percent. These values however, do not reflect the fact that the uncracked PCC pavements are presently distressed. If a sound PCC layer (EPCC = 5000 ksi) is assumed, the reduction in the equivalent thickness is approximately equal to 28 percent.

- While the comparison of layer moduli for the uncracked sections (with AC overlay and without AC overlay) showed a significant difference of 21.5 percent between the two, the difference in the equivalent AC and PCC thickness was only 9.7 and 7.8 percent, respectively.

- Based upon the first two observations, the condition factor, Cb, for converting cracked and seated PCC layers into an equivalent thickness of sound PCC is Cb = 0.7 to 0.75. This value has good agreement with the FAA's condition factor of Cb = 0.75 (minimum allowed value in the design of flexible overlays over rigid pavements) for slabs containing multiple cracking.

- The factor for converting cracked and seated PCC layers into an equivalent thickness of high quality asphaltic concrete is 1.2 to 1.3. For example, 6 inches of cracked and seated PCC are approximately equal to (1.25 x 6 inches =) 7.5 inches of high quality AC.

- The conversion factors noted above are based on an average elastic modulus of 1920 ksi for the cracked and seated PCC. This value, as noted earlier, is higher than the AASHTO recommended range of 500 to 1000 ksi. If the recommended range of values is used, the corresponding conversion factors are 0.5 to 0.6 and 0.8 to 1.0 for equivalent PCC and AC thicknesses, respectively.

TABLE 20

EQUIVALENT AC THICKNESSES

Construction Type	Equivalent AC Thickness (inches) PCC Layer	Total Pavement
1. Cracked/Seated PCC (with AC Overlay)	7.6	10.4
2. Uncracked PCC		
a. With AC Overlay	10.1	11.9 (11.6 to 12.1)
b. Without AC OVerlay	9.3	9.3

TABLE 21

EQUIVALENT PCC THICKNESSES

Construction Type	Equivalent PCC Thickness (inches) PCC Layer	Total Pavement
1. Cracked/Seated PCC (with AC Overlay)	4.36	5.93
2. Uncracked PCC		
a. With AC Overlay	5.74	6.74 (6.60 to 6.88)
b. Without AC Overlay	5.29	5.29

- The equivalent thicknesses presented in Tables 21 and 22 for the total pavement are somewhat misleading due to the fact that variable AC overlay thicknesses (0 to 2.75 inches) were used in each section. For example, the equivalent PCC thickness of the cracked and seated section is 5.93 and that of the uncracked section without an overlay is 5.29. The cracked and seated section however, has a 2.75 inch overlay which results in a 1.57 inch increase in the equivalent PCC thickness. Therefore, care must be exercised when comparing the strucural capacity of these pavements.

- While the equivalent thickness values for the total pavement are not very useful for comparing the structural capacity of cracked and seated versus uncracked PCC layers, they are (or can be) extremely useful in the design of overlays. This fact is illustrated in the ensuing section where a complete overlay analysis is presented.

- Based upon the results of the analysis, the cracked and seated pavement was shown to have a higher modulus (hence structural capacity) than that of high quality AC material but lower than that of a sound PCC slab. This, combined with the NDT deflection basin slopes, led to the conclusion that the cracked and seated PCC layer is behaving as a semi-rigid material.

OVERLAY ANALYSIS

The primary purpose of this analysis was to design asphaltic concrete overlays for the three pavement construction types at Suffolk Municipal Airport assuming equivalent traffic conditions. This overlay analysis was performed using FAA procedures outlined in AC-150/5320-6C "Airport Pavement Desig and Evaluation". The Asphalt Institute's (TAI) Manual Series No. 11 "Full Depth Asphalt Pavements for Air Carrier Airports" was also used in the analysis.

The results of the material characterization and structural capacity analysis were integrated into the overlay analysis in terms of equivalent (AC or PCC) thicknesses. The overlay analysis approach used in this study assumes that as a pavement uses part of its life (as a result of traffic and environmental conditions over time) it behaves as if it were an increasingly thinner pavement. In other words, its effective thickness becomes less and less to account for the used portion of the total life of the pavement.

Furthermore, the equivalent pavement thickness required to carry the expected traffic under a given set of subgrade and environmental conditions can be determined using the FAA's (flexible or rigid) or TAI's (flexible) design procedures.

Therefore, the required overlay thickness is simply the difference between the thickness required for a new pavement (to withstand the estimated future traffic) and the effective thickness of the existing pavement.

In the ensuing paragraphs, a discussion of the most important factors and procedures used to calculate the required overlay thicknesses is presented. In addition, a comparison of the results is made.

Subgrade Characterization

The subgrade moduli (ESG) for the pavements at Suffolk Municipal Airport are summarized, according to construction type, in Table 17. As noted earlier, these ESG values were calculated using the results of the NDT testing program as input into the PCS EMOD computer program.

While no comparison of the subgrade moduli was made, it is apparent from Table 17 that the range of values is small. However, these values give an indication of the subgrade support capabilities at the time of testing only (unique set of moisture and temperature conditions). Therefore, instead of one average value, a range of subgrade moduli was used in the overlay analysis. This range, shown in Table 22, addresses the effects of not only variable climatic conditions

but also material variability upon the subgrade support (and hence pavement performance).

The range of subgrade moduli presented in Table 22 can be directly input into the TAI design procedure. However, the FAA procedure requires that the subgrade characteristics be defined in terms of a California Bearing Ratio (CBR) value for flexible pavements or a modulus of subgrade reaction (k) for rigid pavements. In view of this, E-CBR and E-k correlations available in the literature were used.

In this study, the widely used expression relating modulus to CBR is that developed by the Shell Oil Co. (Heukelom and Foster):

$$E\ (\text{ksi}) = 1.5 * \text{CBR}\ (\%)$$

The correlation used in this project to relate elastic modulus (E) to the k value is the relationship developed by the U.S. Army Corps of Engineers, shown below:

$$k\ (\text{pci}) = 10^{x}$$

where:

$$x = (\log E - 1.415)/1.284$$

with E in units of pounds per square inch.

The corresponding CBR and k values for the assumed range of subgrade moduli are also shown in Table 22.

<u>Traffic Characteristics</u>

As noted earlier, one major assumption in the overlay analysis was that of equal traffic conditions for the pavements under investigation. With this in mind, the conditions shown below were used in the analysis to predict the required overlay thicknesses.

Aircraft type - required overlay thicknesses were separately calculated for a (1) 30 kip single wheel, (2) 50 kip dual wheel, (3) 100 kip dual tandem, (4) DC-9-41, (5) B-727-200, and (6) DC-8-63F aircraft. The characteristics of the last three aircraft are presented in Table 23.

Annual departures - a constant value of 1200 annual departures was assumed for each of the six aircraft under consideration.

TABLE 22

SUBGRADE CHARACTERISTICS

Subgrade Modulus (Ksi) E_{SG}	Subgrade CBR (%) CBR_{SG}	Modulus of Subgrade Reaction (pci) K_{SG}
7.5	5	82.4
10.5	7	107.1
15.0	10	141.4
22.5	15	193.9
30.0	20	242.6

TABLE 23

CHARACTERISTICS OF AIRCRAFTS USED IN OVERLAY ANALYSES

	Aircraft		
	1	2	3
Aircraft	DC-9-41	B-727-200	DC-8-63F
Gross Weight of aircraft (kips)	115.0	173.0	358
Main gear type	Dual	Dual	Dual tandem
Main gear weight (kips)	53.8	79.9	172
Tire spacing (inches)	26	34	32 x 55
Weight per tire (kips)	26.9	39.9	43
Tire pressure (psi)	163	168	196

Overlay Design - FAA Flexible Pavement Approach

The design of flexible airfield pavements using FAA procedures is outlined in AC-150/5320-6C "Airport Pavement Design and Evaluation", pages 37 through 60.

In this procedure, the design curves shown in Figure 8 through 10 are used to predict the required pavement thickness based on the gross aircraft weight, number of annual departures and subgrade CBR value. The predicted thickness is then used to develop the final cross section based on the (1) minimum AC surface thickness (as a function of area type), (2) minimum base thickness (see Figure 11), and (3) properties (CBR) of the material in combination with the design curves. Furthermore, the use of substitution ratios (shown in Table 24 and 25) allows the designer to convert granular material into equivalent thicknesses of stabilized materials (such as bituminous surface course).

Using this procedure, the required equivalent AC thickness for all combinations of subgrade CBR (Table 22) and aircraft type (Table 23) were calculated. The resulting values are presented in Table 26. Also shown in this table are the required overlay thicknesses for two cases:

Case I. Using the existing equivalent AC thickness of the total pavement (i.e., including any AC overlays; see Table 21)

Case II. Using the existing equivalent AC thickness of the PCC layer (i.e., assuming there are no overlays; see Table 21).

These overlay thicknesses were calculated by subtracting the existing equivalent AC thickness from the required equivalent AC thickness.

Overlay Design - TAI Flexible Pavement Approach

The design of flexible airfield pavements using TAI procedures is outlined in Manual Series No. 11 "Full-Depth Asphalt Pavements for Air Carrier Airports".

In this procedure, estimates of the subgrade modulus, mean annual air temperature, and projected forecast of aircraft traffic mix are first made. Next, the predicted number of equivalent DC-8-63F repetitions to failure (based on two criteria: tensile strain at the bottom of the asphalt layer and compressive strain at the top of the subgrade) are calculated for the traffic mix at various equivalent AC thicknesses (see example in Figures 12). The results are then used to develop thickness-equivalent repetitions plots for both strain criteria.

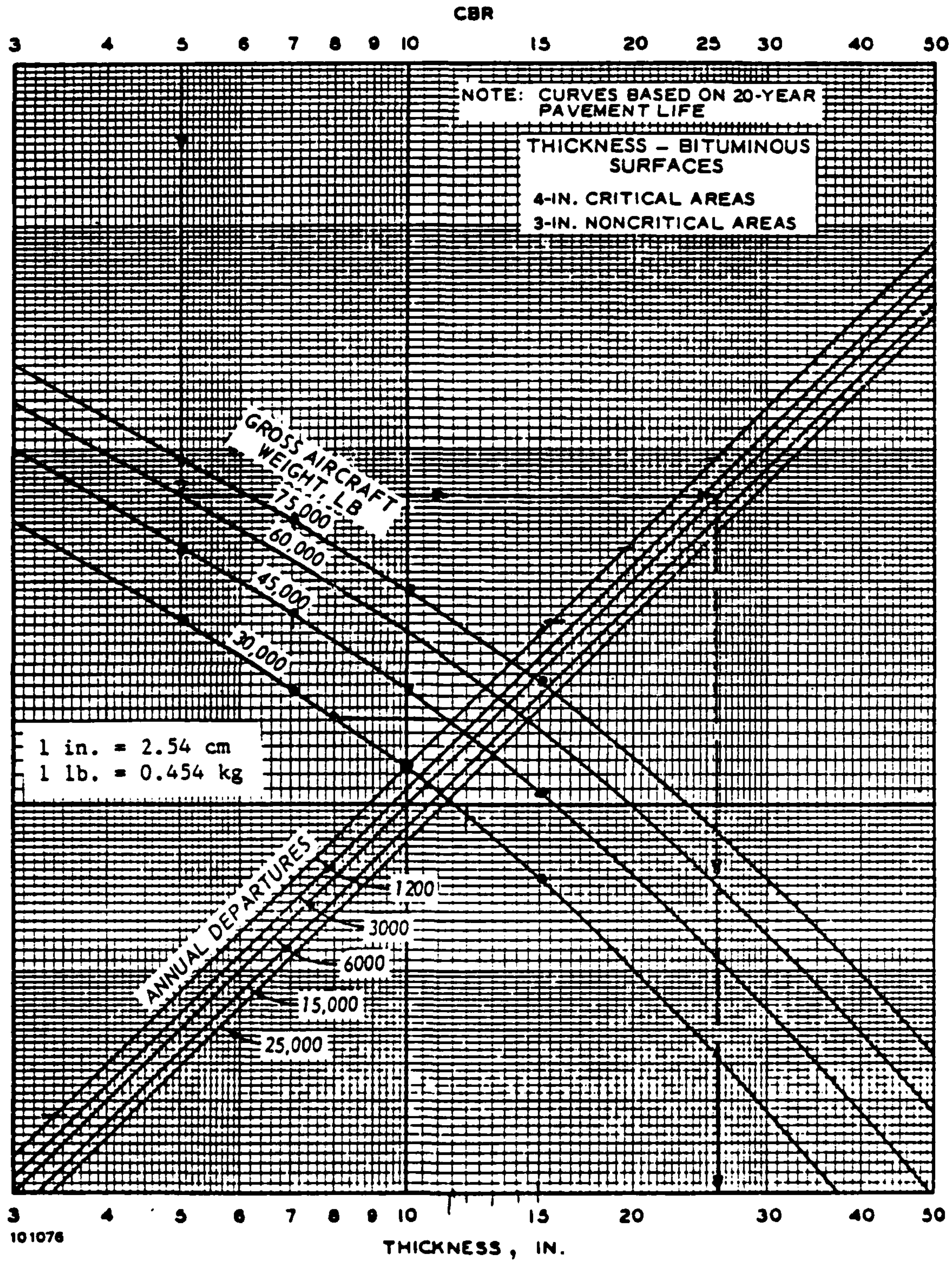


FIGURE 8 FLEXIBLE PAVEMENT DESIGN CURVES FOR CRITICAL AREAS, SINGLE WHEEL GEAR

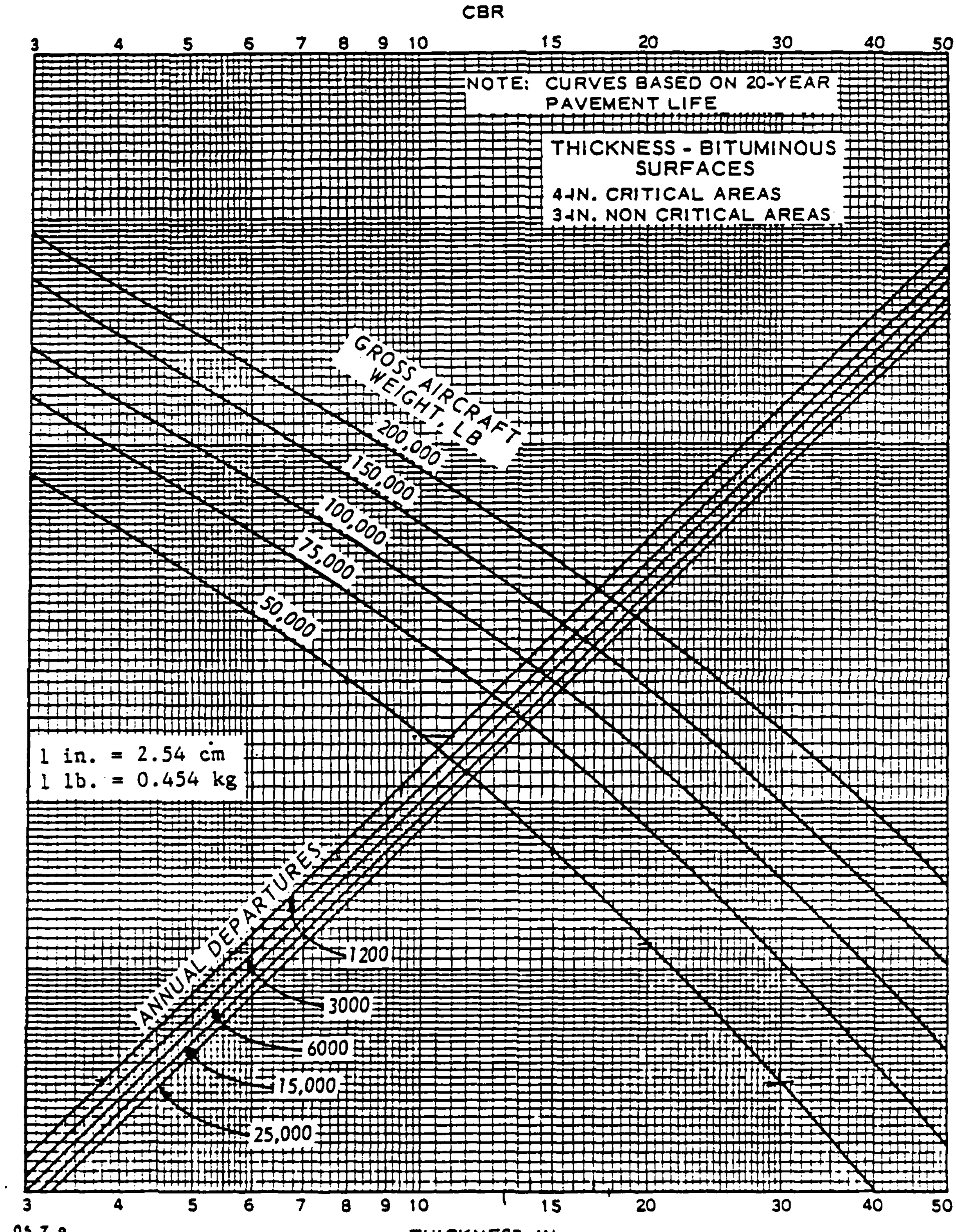


FIGURE 9 FLEXIBLE PAVEMENT DESIGN CURVES FOR CRITICAL AREAS, DUAL WHEEL GEAR

*

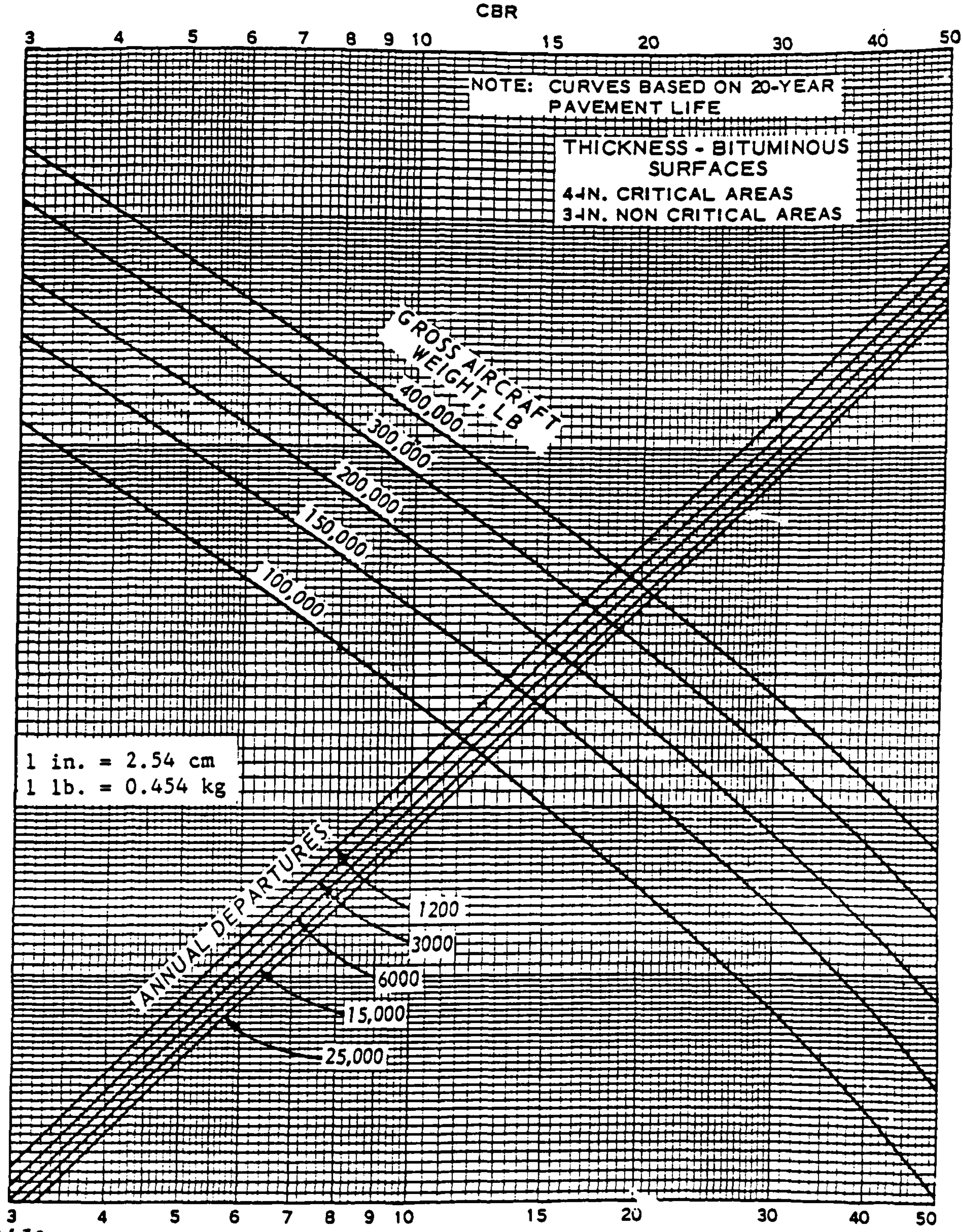


FIGURE 10 FLEXIBLE PAVEMENT DESIGN CURVES FOR CRITICAL AREAS, DUAL TANDEM GEAR

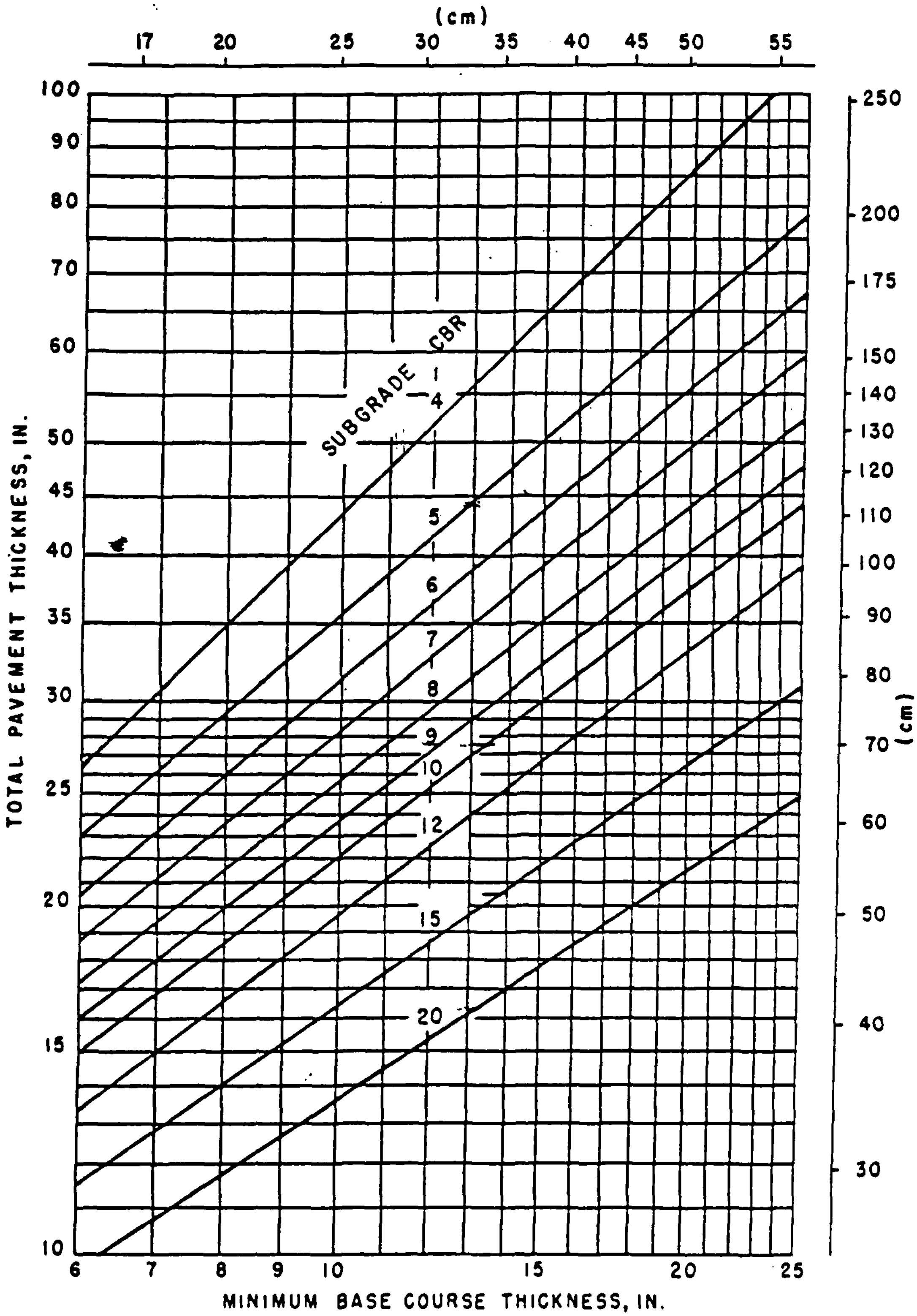


FIGURE 11 MINIMUM BASE COURSE THICKNESS REQUIREMENTS

TABLE 24

RECOMMENDED EQUIVALENCY FACTOR RANGE STABILIZED SUBBASE

Material	Equivalency Factor Range
P-401, Bituminous Surface Course	1.7-2.3
P-201, Bituminous Base Course	1.7-2.3
P-215, Cold Laid Bituminous Base Course	1.5-1.7
P-216, Mixed In-Place Base Course	1.5-1.7
P-304, Cement Treated Base Course	1.6-2.3
P-301, Soil Cement Base Course	1.5-2.0
P-209, Crushed Aggregate Base Course	1.4-2.0
P-154, Subbase Course	1.0

In establishing the equivalency factors shown above the CBR of the standard subbase, P-154 was assumed to be 20.

TABLE 25

RECOMMENDED EQUIVALENCY FACTOR RANGE STABILIZED BASE

Material	Equivalency Factor Range
P-401, Bituminous Surface Course	1.2-1.6
P-201, Bituminous Base Course	1.2-1.6
P-215, Cold Laid Bituminous Base Course	1.0-1.2
P-216, Mixed In-Place Base Course	1.0-1.2
P-304, Cement Treated Base Course	1.2-1.6
P-301, Soil Cement Base Course	N/A
P-209, Crushed Aggregate Base Course	1.0
P-154, Subbase Course	N/A

The equivalency factors shown above assume a CBR value of 80 for P-209.

TABLE 26

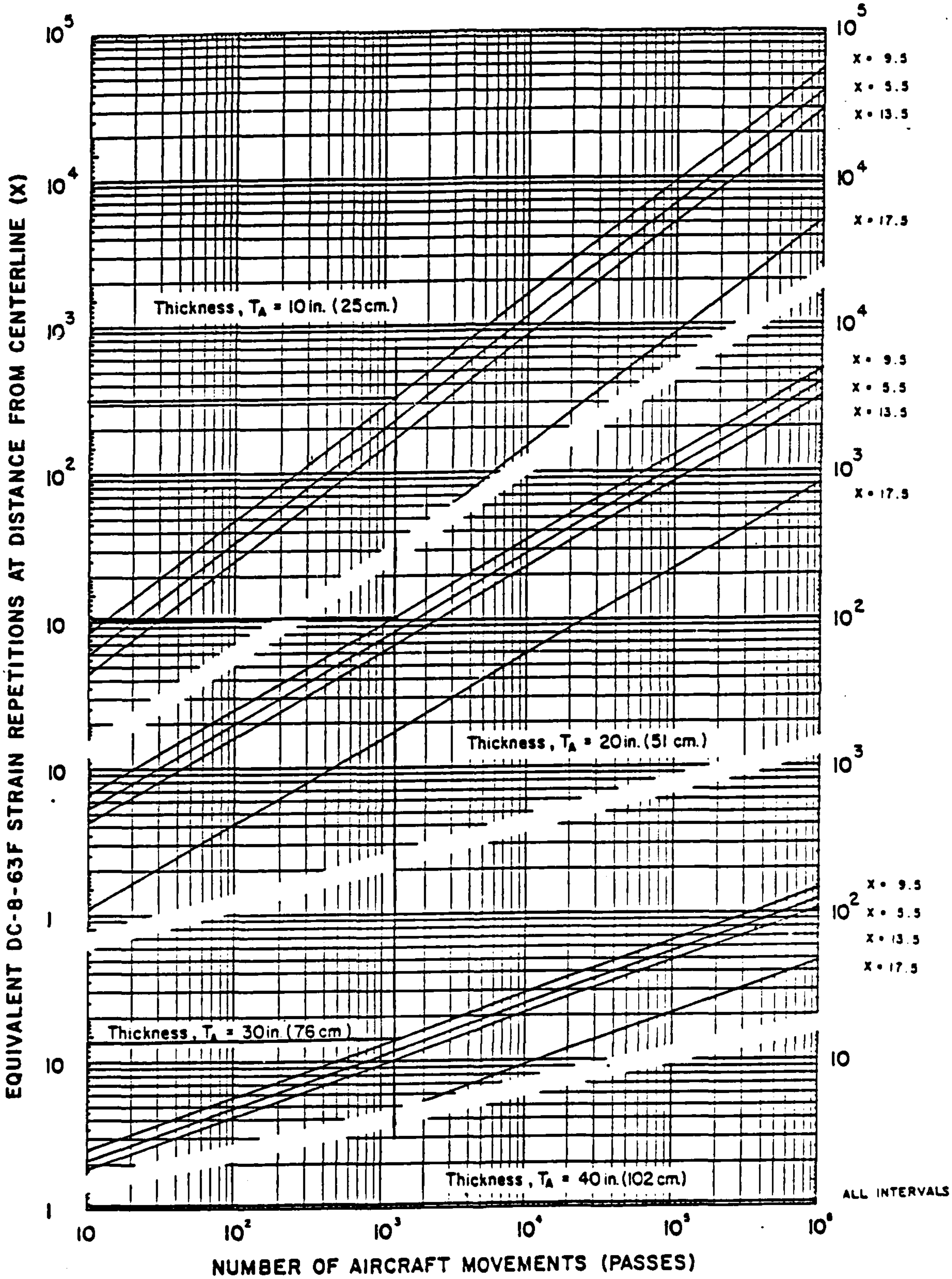
OVERLAY DESIGN - FAA FLEXIBLE PAVEMENT APPROACH

Aircraft Type	Subgrade CBR (%)	Equivalent AC Thickness Required (inches)	Overlay Thickness Required (inches) Case I 1*	Case I 2*	Case I 3*	Case II 1*	Case II 2*	Case II 3*
Single Wheel	5	10.1	0.0	0.0	0.8	2.5	0.0	0.8
	7	8.8	0.0	0.0	0.0	1.2	0.0	0.0
	10	7.8	0.0	0.0	0.0	0.2	0.0	0.0
	15	7.8	0.0	0.0	0.0	0.2	0.0	0.0
	20	7.8	0.0	0.0	0.0	0.2	0.0	0.0
Dual Wheel	5	11.1	0.7	0.0	1.8	3.5	1.0	1.8
	7	9.6	0.0	0.0	0.3	2.0	0.0	0.3
	10	8.2	0.0	0.0	0.0	0.6	0.0	0.0
	15	7.8	0.0	0.0	0.0	0.2	0.0	0.0
	20	7.8	0.0	0.0	0.0	0.2	0.0	0.0
Dual Tandem	5	12.3	1.9	0.4	3.0	4.7	2.2	3.0
	7	10.4	0.0	0.0	1.1	2.8	0.3	1.1
	10	8.8	0.0	0.0	0.0	1.2	0.0	0.0
	15	7.8	0.0	0.0	0.0	0.2	0.0	0.0
	20	7.8	0.0	0.0	0.0	0.2	0.0	0.0

*1 = Cracked/Seated PCC with AC Overlay
2 = Uncracked PCC with AC Overlay
3 = Uncracked PCC without AC Overlay

TABLE 26 (Cont'd)

Aircraft Type	Subgrade CBR (%)	Equivalent AC Thickness Required (inches)	Overlay Thickness Required (inches) Case I			Case II		
			1*	2*	3*	1	2	3
DC-9-41	5	15.6	5.0	3.7	6.3	8.0	5.5	6.3
	7	13.5	2.9	1.6	4.2	5.9	3.4	4.2
	10	11.5	0.9	0.0	2.2	3.9	1.4	2.2
	15	9.6	0.0	0.0	0.3	2.0	0.0	0.0
	20	8.4	0.0	0.0	0.0	0.8	0.0	0.0
B-727-200	5	16.8	6.2	4.9	7.5	9.2	6.7	7.5
	7	14.8	4.2	2.9	5.5	7.2	4.7	5.5
	10	12.7	2.1	0.8	3.4	5.1	2.6	3.4
	15	10.5	0.0	0.0	1.2	2.9	0.4	1.2
	20	9.0	0.0	0.0	0.0	1.4	0.0	0.0
DC-8-63F	5	23.9	13.3	12.0	14.6	16.3	13.8	14.6
	7	20.0	9.4	8.1	10.7	12.4	9.9	10.7
	10	16.8	6.2	4.9	7.5	9.2	6.7	7.5
	15	13.8	3.2	1.9	4.5	6.2	3.7	4.5
	20	12.1	1.5	0.2	2.8	4.5	2.0	2.8



AIRCRAFT: B-727-200 STRAIN CRITERION: ϵ_c

FIGURE 12. PREDICTED EQUIVALENT DC-8-63F REPETITIONS

Based on the subgrade modulus and mean annual air temperature, the allowable number of equivalent DC-8-63F repetitions is calculated for both strain criteria as a function of the equivalent AC thickness (see example in Figures 13 and 14). Again, thickness-equivalent repetition curves are developed.

Superimposing the predicted and allowable equivalent repetition versus thickness plots (see Figure 15), the required equivalent AC thickness for both strain criteria is defined by the intersection of the curves. The final design thickness used is the greater of the two thicknesses calculated in the previous step (i.e., intersection of plots).

Using this procedure, the required equivalent AC thickness for all combinations of subgrade modulus (Table 23) and three aircraft types (DC-9-41, B-727-200, and DC-8-63F) was calculated. The resulting thickness values are presented in Table 27 for the same two cases used in the FAA flexible pavement procedure.

Overlay Design - FAA Rigid Pavement Approach

The design of bituminous overlays on existing rigid pavements using FAA procedures is outlined in AC-150/5320-6C "Airport Pavement Design and Evaluation", pages 101 through 109. This procedure was used in this study only as a research tool; it is not recommended by the FAA for the design of overlays on cracked and seated pavements.

In this procedure, the thickness of the bituminous overlay is computed from the following equation:

$$t = 2.5\,(F \times h - Cb \times he)$$

where:

- t = thickness of bituminous overlay, in inches,
- F = factor which controls the degree of cracking which will occur in the pavement (see Figure 16),
- h = PCC pavement thickness required for design conditions,
- Cb = condition factor of base pavement, and
- he = thickness of existing rigid pavement.

In this equation, the value of "h" is found from the design charts shown in Figures 17 through 19 as a function of the gross aircraft weight, annual departures, modulus of subgrade reaction, and concrete flexural strength. Also, it should be noted that

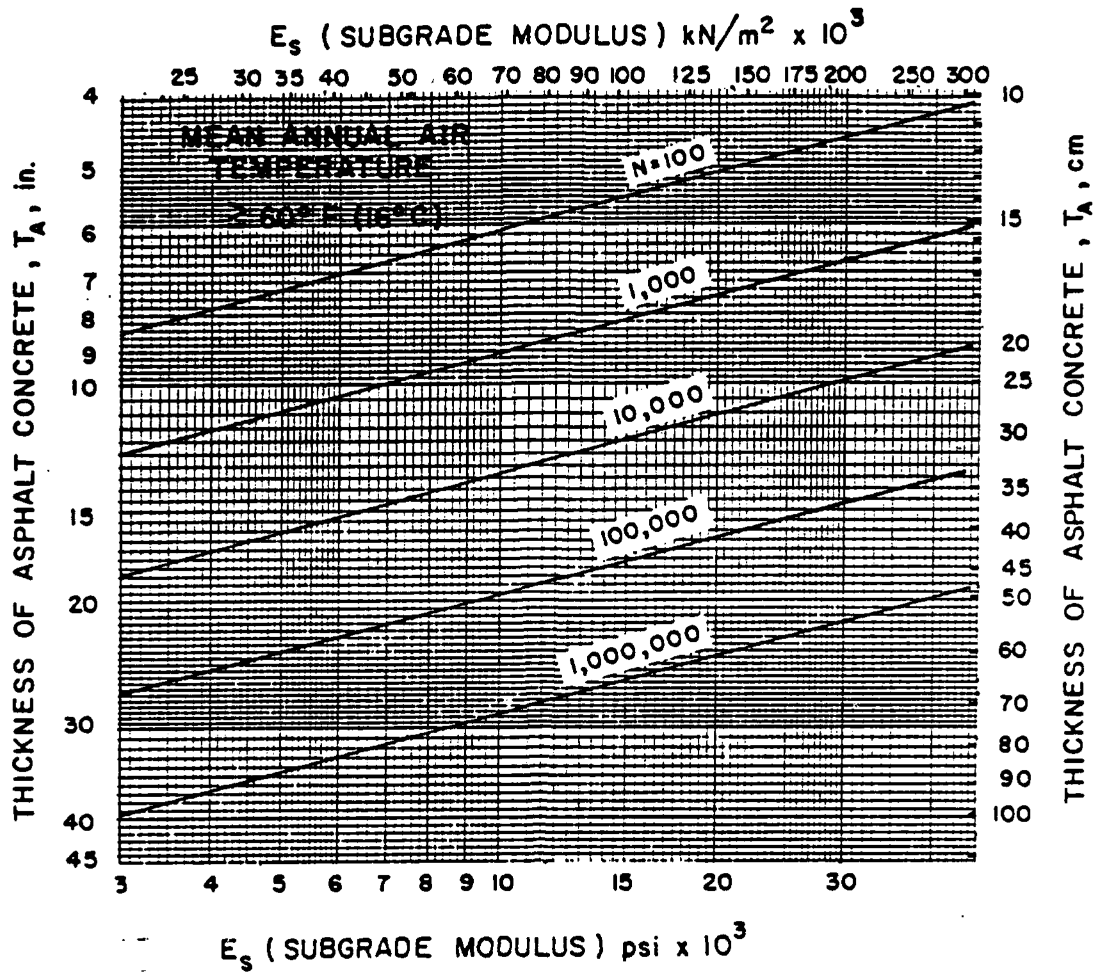


FIGURE 13. Pavement thickness to limit asphalt concrete horizontal tensile strain, ε_t, under DC-8-63F load repetitions for different environments

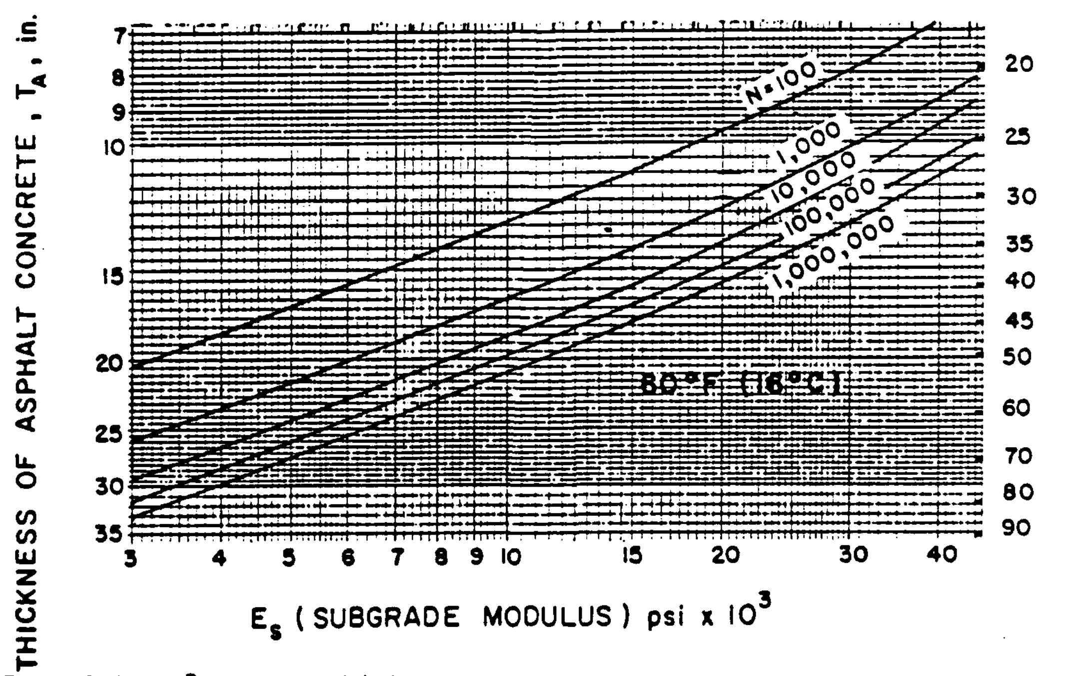


FIGURE 14. Pavement thickness to limit subgrade vertical compressive strain, ε_t, under DC-8-63F load repetitions for different environments

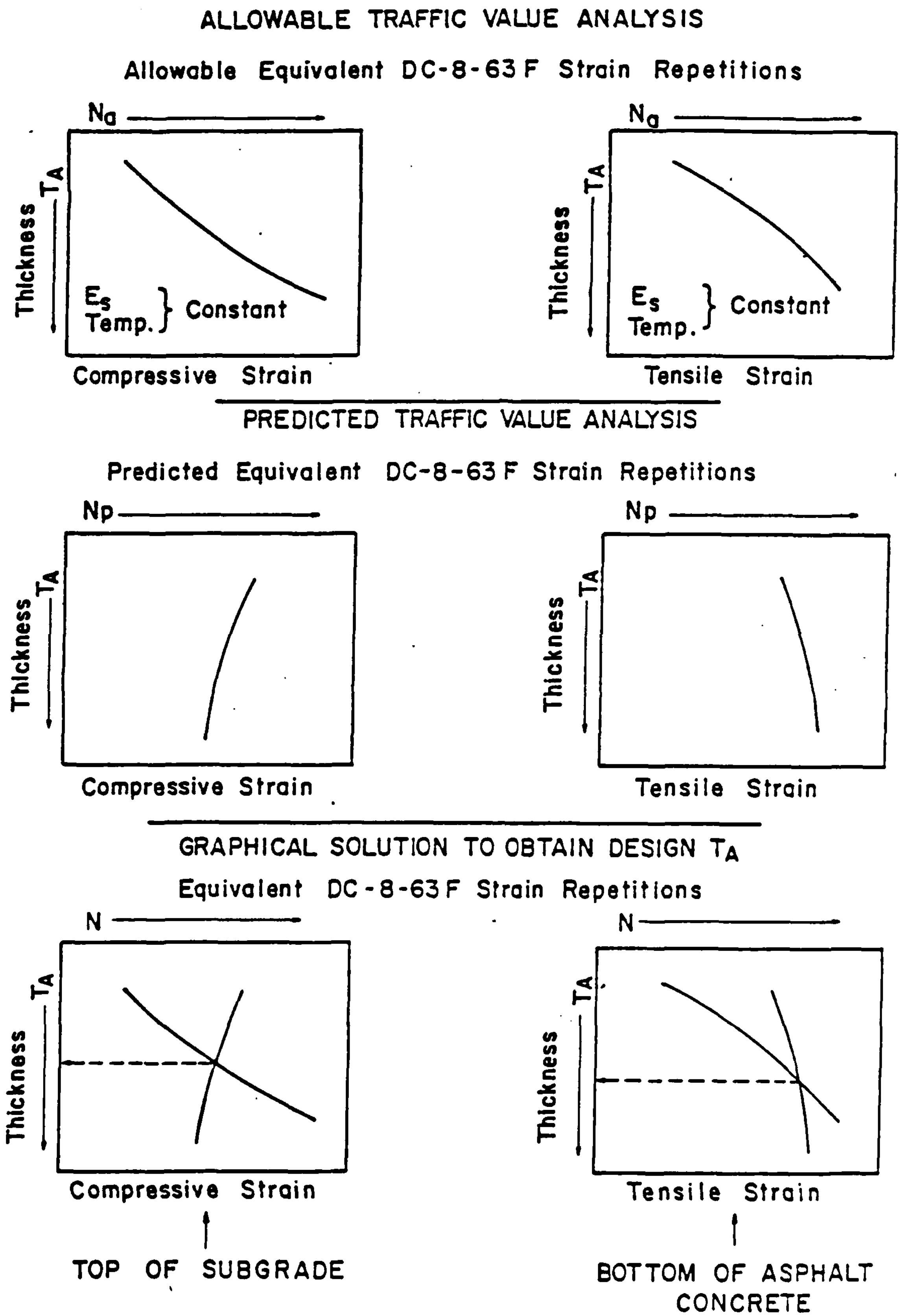


FIGURE 15. EQUIVALENT AC THICKNESS SOLUTION

TABLE 27

OVERLAY DESIGN - TAI FLEXIBLE PAVEMENT APPROACH

Aircraft Type	Subgrade CBR (%)	Equivalent AC Thickness Required (inches)	Overlay Thickness Required (inches) Case I 1*	Case I 2*	Case I 3*	Case II 1	Case II 2	Case II 3
DC-9-41	5	13.5	3.1	1.6	4.2	5.9	3.4	4.2
	7	12.0	1.6	0.1	2.7	4.4	1.9	2.7
	10	10.5	0.1	0.0	1.2	2.9	0.4	1.2
	15	8.5	0.0	0.0	0.0	0.9	0.0	0.0
	20	7.5	0.0	0.0	0.0	0.0	0.0	0.0
B-727-200	5	16.0	5.6	4.1	6.7	8.4	5.9	6.7
	7	14.0	3.6	2.1	4.7	6.4	3.9	4.7
	10	12.0	1.6	0.1	2.7	4.4	1.9	2.7
	15	10.5	0.1	0.0	1.2	2.9	0.4	1.2
	20	9.0	0.0	0.0	0.0	1.4	0.0	0.0
DC-8-63F	5	18.5	8.1	6.6	9.2	10.9	8.4	9.2
	7	16.2	5.8	4.3	6.9	8.6	6.1	6.9
	10	14.1	3.7	2.2	4.8	6.5	4.0	4.8
	15	11.6	1.2	0.0	2.3	4.0	1.5	2.3
	20	10.2	0.0	0.0	0.9	2.6	0.1	0.9

*1 = Cracked/Seated PCC with AC Overlay
2 = Uncracked PCC with AC Overlay
3 = Uncracked PCC without AC Overlay

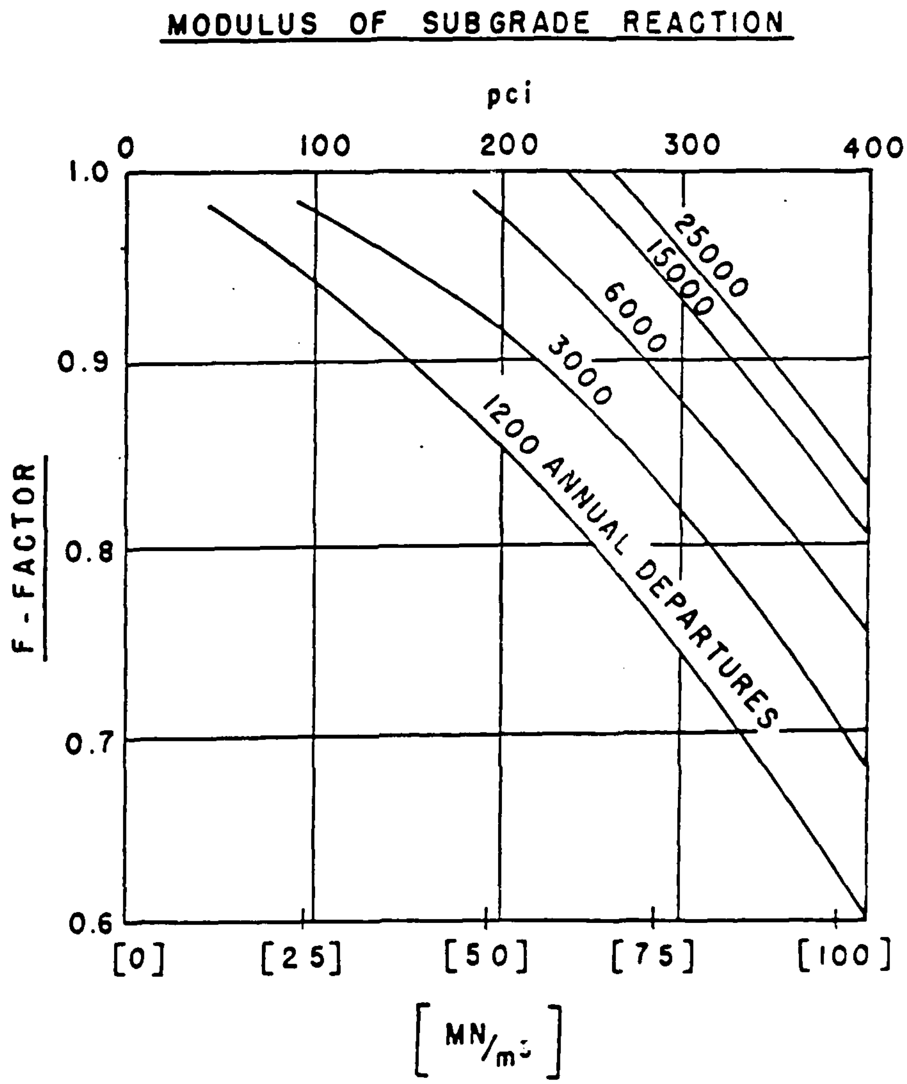
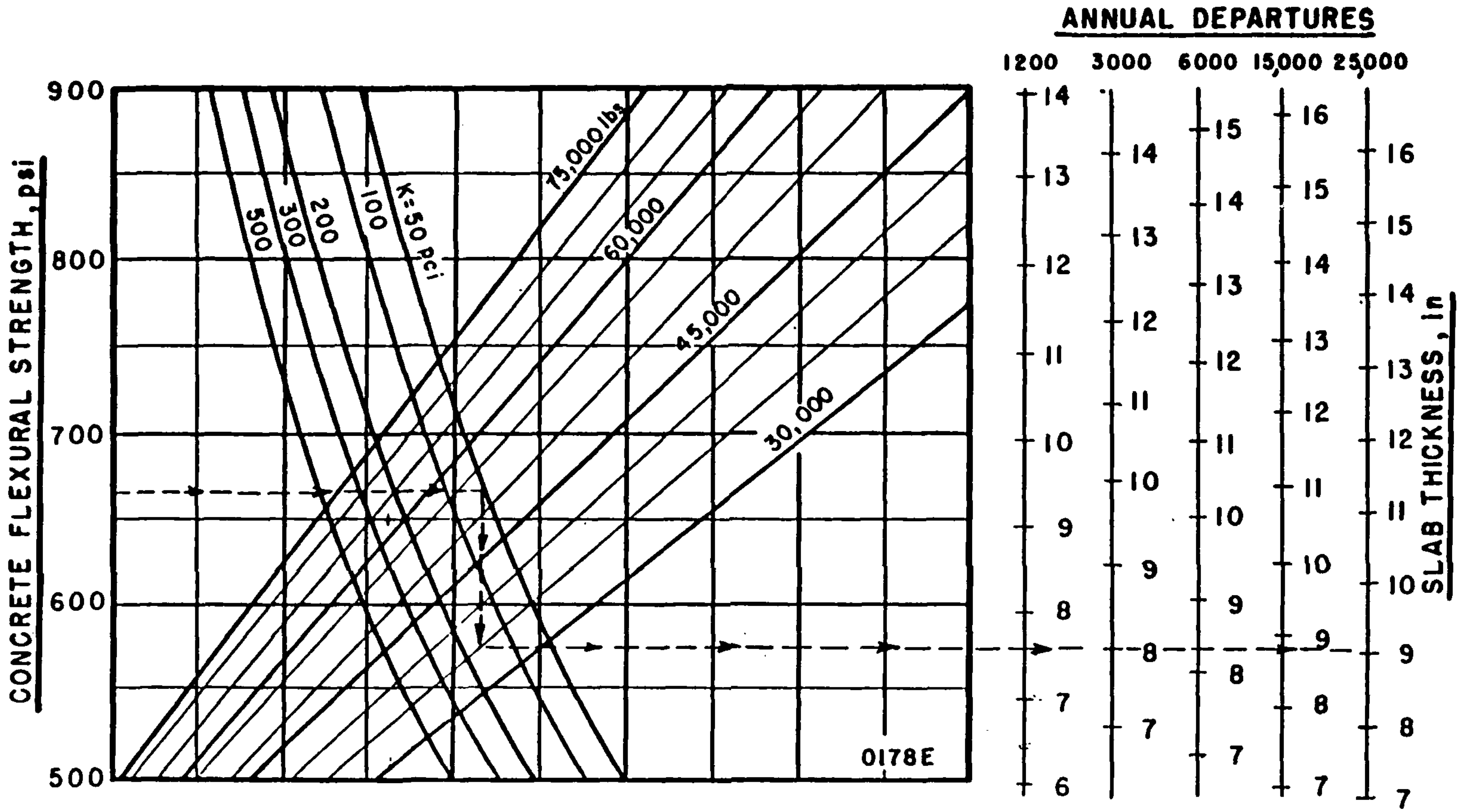


FIGURE 16 GRAPH OF "F" FACTOR VS. MODULUS OF SUBGRADE REACTION FOR DIFFERENT TRAFFIC LEVELS



NOTE:

1 inch = 2.54 cm   1 psi = 0.0069 MN/m²

1 lb = 0.454 kg   1 pci = 0.272 MN/m³

FIGURE 17 RIGID PAVEMENT DESIGN CURVES - SINGLE WHEEL GEAR

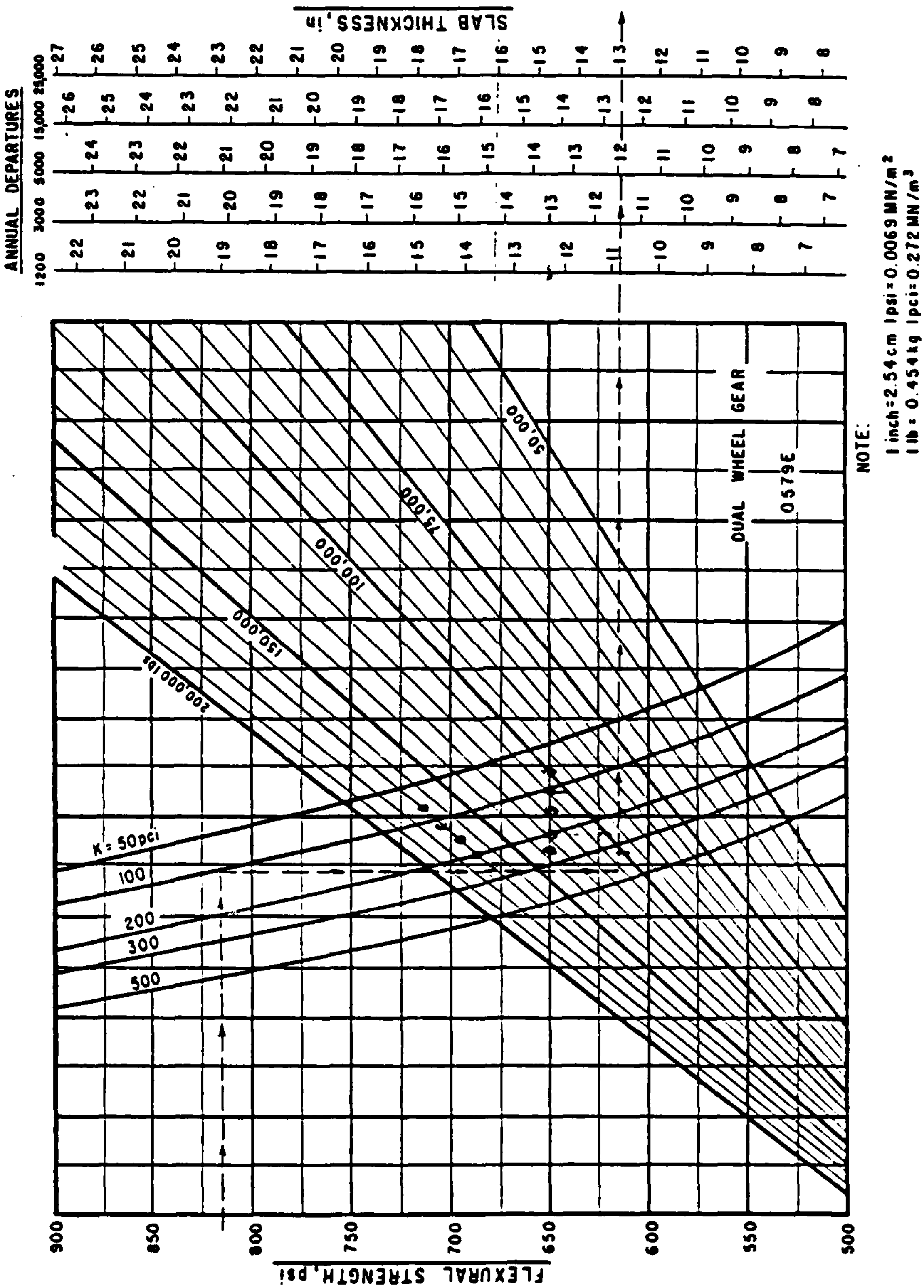
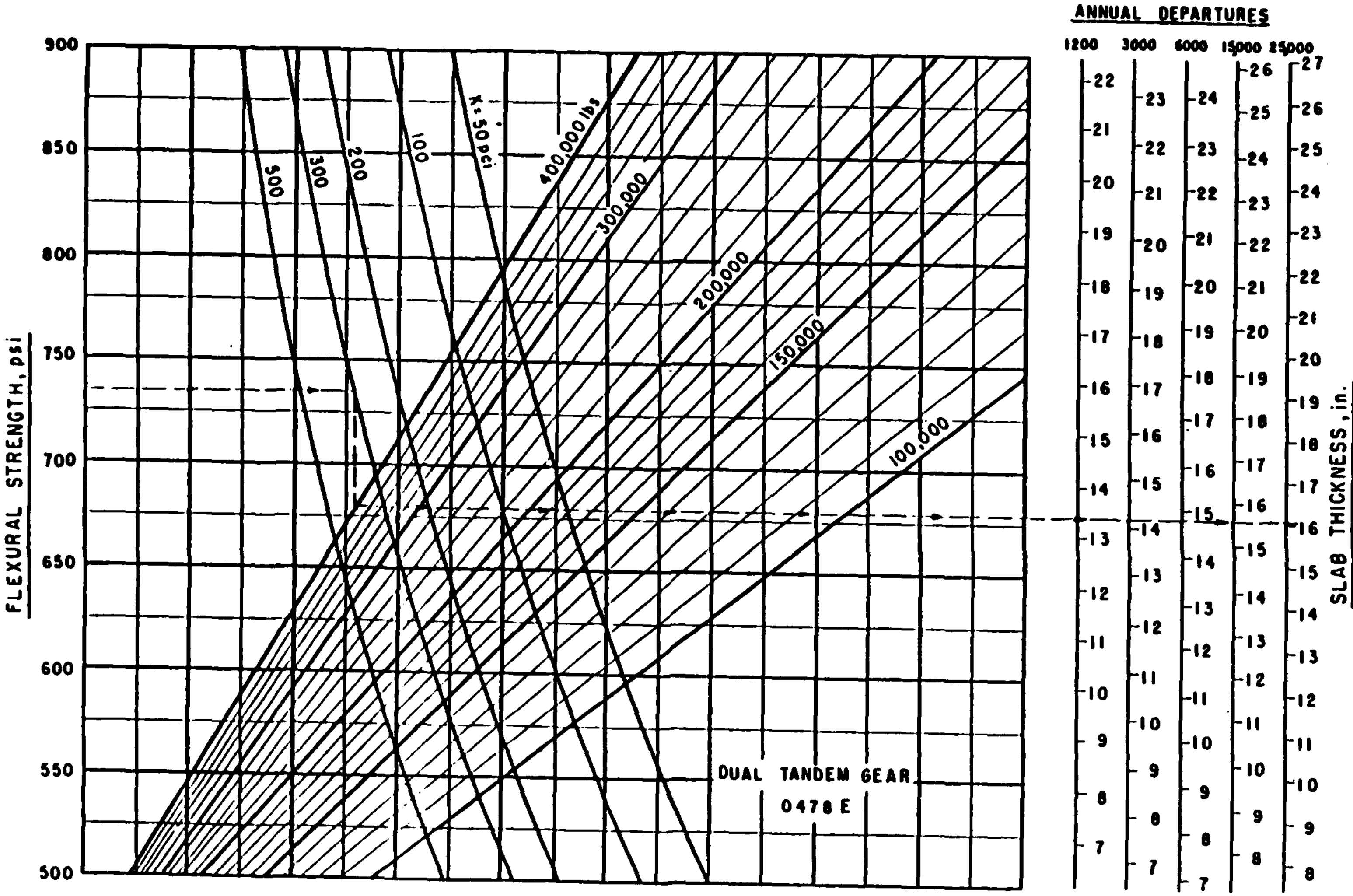


FIGURE 18 RIGID PAVEMENT DESIGN CURVES - DUAL WHEEL GEAR



NOTE:
1 inch = 2.54 cm 1 psi = 0.0069 MN/m²
1 lb = 0.454 kg 1 pci = 0.272 MN/m³

FIGURE 19 RIGID PAVEMENT DESIGN CURVES - DUAL TANDEM GEAR

the multiplication of the factors "Cb x he" represents the equivalent PCC thickness of the existing pavement.

Using the above equation, the required AC overlay thickness was calculated for all combinations of aircraft type (Table 23), modulus of subgrade reaction (Table 22), and equivalent PCC thickness of the existing pavement (Table 21; Case I - based on total pavement and Case II - based on PCC layer only). The resulting thicknesses are presented in Table 28.

<u>Comparison of Overlay Thicknesses</u>

In preceding section, the required AC overlay thickness for various combinations of subgrade support and aircraft type was calculated for the pavements at Suffolk Municipal Airport using three different approaches: FAA flexible, TAI flexible, and FAA rigid design procedures. The results were summarized in Tables 26, 27, and 28.

Based upon these results, the following observations were made:

- The required overlay thickness, as would be expected, increases as the subgrade strength and/or effective structural capacity of the existing pavement decreases.

- The largest required overlay thicknesses were those predicted by the FAA rigid design approach, followed by the FAA flexible and TAI flexible design procedures.

- The best agreement in the predicted overlay thicknesses is that between the FAA flexible and TAI flexible design procedures.

- Assuming that no AC overlays are present on the existing pavements (i.e., Case II), the required overlay thicknesses predicted by the FAA rigid design procedure exceed the thickness of the PCC layer in the majority of the cases. This is particularly true for the cracked and seated pavement. For such cases, the FAA recommends designing the overlay as a flexible pavement and treating the existing rigid pavement as a high quality base material.

- Based upon the results of the study and the observations noted up to this point, it is provisionally recommended that a modified FAA flexible design procedure be used in the interim, for the design of AC overlays, with crack/seat rehabilitation approaches.

TABLE 28

OVERLAY DESIGN - FAA RIGID PAVEMENT APPROACH

Aircraft Type	Modulus of Subgrade Reaction (PCI)	"F" Factor	Equivalent PCC Thickness Required (inches)	AC Overlay Thickness Required (inches) Case I			Case II		
				1*	2*	3*	1	2	3
Single Wheel	82.4	0.96	6.9	1.8	0.0	3.3	5.7	2.2	3.3
	107.1	0.94	6.7	1.0	0.0	2.5	4.8	1.4	2.5
	141.4	0.91	6.5	0.0	0.0	1.6	3.9	0.4	1.6
	193.9	0.86	6.3	0.0	0.0	0.3	2.6	0.0	0.3
	242.6	0.80	6.2	0.0	0.0	0.0	1.5	0.0	0.0
Dual Wheel	82.4	0.96	8.0	4.5	2.4	6.0	8.3	4.9	6.0
	107.1	0.94	7.8	3.5	1.5	5.1	7.4	4.0	5.1
	141.4	0.91	7.5	2.3	0.2	3.8	6.2	2.7	3.8
	193.9	0.86	7.2	0.8	0.0	2.3	4.6	1.1	2.3
	242.6	0.80	7.0	0.0	0.0	0.8	3.1	0.0	0.8
Dual Tandem	82.4	0.96	9.5	8.0	6.0	9.6	11.9	8.5	9.6
	107.1	0.94	9.1	6.5	4.5	8.2	10.5	7.0	8.2
	141.4	0.91	8.7	5.0	2.9	6.6	8.9	5.4	6.6
	193.9	0.86	8.3	3.0	1.0	4.6	6.9	3.5	4.6
	242.6	0.80	8.0	1.3	0.0	2.8	5.1	1.7	2.8

*1 = Cracked/Seated PCC with AC Overlay
2 = Uncracked PCC with AC Overlay
3 = Uncracked PCC without AC Overlay

TABLE 28 (Cont'd)

Aircraft Type	Modulus of Subgrade Reaction (PCI)	"F" Factor	Equivalent PCC Thickness Required (inches)	AC Overlay Thickness Required (inches) Case I			Case II		
				1	2	3	1	2	3
DC-9-41	82.4	0.96	12.5	15.2	13.2	16.8	19.1	15.7	16.8
	107.1	0.94	12.0	13.4	11.4	15.0	17.3	13.9	15.0
	141.4	0.91	11.5	11.3	9.3	12.9	15.3	11.8	12.9
	193.9	0.86	11.0	8.8	6.8	10.4	12.8	9.3	10.4
	242.6	0.80	10.5	16.2	4.2	7.8	10.1	6.7	7.8
B-727-200	82.4	0.96	14.9	20.9	18.9	22.5	24.9	21.4	22.5
	107.1	0.94	14.5	19.3	17.2	20.9	23.2	19.7	20.9
	141.4	0.91	14.1	18.2	16.1	19.8	22.1	18.6	19.8
	193.9	0.86	13.8	14.8	12.8	16.4	18.8	15.3	16.4
	242.6	0.80	13.4	12.0	10.0	13.6	15.9	12.4	13.6
DC-8-63F	82.4	0.96	16.5	24.8	22.8	26.4	28.7	25.3	26.4
	107.1	0.94	15.9	22.5	20.5	24.1	26.5	23.0	24.1
	141.4	0.91	15.2	19.8	17.7	21.4	23.7	20.2	21.4
	193.9	0.86	14.5	16.4	14.3	18.0	20.3	16.8	18.0
	242.6	0.80	13.9	13.0	11.0	14.6	16.9	13.4	14.6

TABLE 29

RECOMMENDED AC OVERLAY THICKNESSES

(Based on 1200 annual departures)

Aircraft Type	Subgrade CBR(%)	Overlay* Thickness (in.)	Aircraft Type	Subgrade CBR(%)	Overlay* Thickness (in.)
Single Wheel	5	2.5	DC-9-41	5	8.0
	7	1.2		7	5.9
	10	0.2		10	3.9
	15	0.2		15	2.0
	20	0.2		20	0.8
Dual Wheel	5	3.5	B-727-200	5	9.2
	7	2.0		7	7.2
	10	0.6		10	5.1
	15	0.2		15	2.9
	20	0.2		20	1.4
Dual Tandem	5	4.7	DC-8-63F	5	16.3
	7	2.8		7	12.4
	10	1.2		10	9.2
	15	0.2		15	6.2
	20	0.2		20	4.5

*These values do not take into account any specifications for the minimum required AC surface/overlay thickness.

Such an approach would be similar to that used in this study:

- Evaluate existing pavement (using NDT testing, condition distress surveys, etc.).

- Assess the condition of the cracked and seated PCC layer (as well as other layers) based on the results of the pavement evaluation.

- Based upon the condition of the cracked and seated PCC (and other layers) calculate the equivalent AC thickness of the PCC layer (and other layers). In this study, for example, a conversion factor of 1.20 to 1.30 was used to transform the cracked and seated PCC into an equivalent AC thickness.

- Determine the overall structural capacity of the existing pavements in terms of an equivalent AC thickness (i.e., summation of individual layer equivalent AC thicknesses).

- Using FAA's flexible pavement design procedure as described in this study, determine the equivalent AC thickness required to carry the projected traffic under a given set of condition (i.e., subgrade strength, environment, etc.).

- Finally, calculate the required overlay AC thickness by subtracting the existing pavement equivalent AC thickness from the required AC thickness.

o Based upon the above procedure, the required overlay thicknesses for the cracked and seated PCC pavement are summarized in Table 29 for all combinations of aircraft type and subgrade CBR. The values shown in this table assume that no AC overlays presently exist and the same number (1200) of annual departures for each aircraft type.

SUMMARY AND CONCLUSIONS

Despite the growing popularity of the crack and seat approach during a period when engineers are faced with unprecedented demands for innovative and economical pavement rehabilitation techniques, little guidance is available for use in evaluating and designing overlays for cracked and seated airfield pavements.

Towards solving this problem, a case study was undertaken to compare the in-situ characteristics, overlay requirements, and performance of three different pavement sections at Suffolk Municipal Airport: one PCC pavement section which was cracked and seated and received an asphaltic concrete overlay; one PCC section which was overlaid without cracking and seating; and a PCC section which was neither cracked and seated nor overlayed. Because these pavement sections are of the same original construction yet received very different rehabilitation measures and are performing differently, an excellent opportunity existed to conduct a comparison study of the PCC layers and develop preliminary recommendations for characterizing cracked and seated PCC layers for design purposes.

In order to accomplish the objectives of this study three major tasks were undertaken. They were: (1) Pavement Evaluation, (2) Material Characterization and Structural Capacity Analysis, and (3) Overlay Analysis.

In the first task, nondestructive testing (NDT) was used to determine the in-situ pavement properties and visual condition surveys were conducted to assess the overall condition rating of the pavements. In Task 2, the results of the NDT testing program were used to predict the layer moduli and structural capacity of the pavements. And, in Task 3, asphaltic concrete overlays were designed for the pavements under investigation assuming equivalent traffic conditions.

Based upon the results generated in this study, the following major conclusions were made:

- While the use of the crack and seat approach to reduce reflective cracking appears to be effective, the results of the visual condition distress survey showed that the problem of reflecting cracking is not eliminated. This conclusion, however, is based on limited data (only one pavement section) collected after only 3 years (i.e., no accurate estimates of the future performance can be made).

- The strength of the PCC layer is significantly reduced after cracking and seating. Based upon the predicted PCC layer moduli (from NDT testing), the reduction in

strength is approximately 60 to 65 percent when compared to that of a sound slab.

- The average elastic modulus of the cracked and seated PCC pavement was found to be 1,920 ksi. Because this value is greater than the AASHTO recommended range of moduli (500 to 1,000 ksi) and the pavement is showing a significant amount of cracking after only 2 to 3 years, the results seem to indicate that a greater degree of cracking before placing the overlay would have been helpful.

- The above conclusion also suggests that perhaps NDT testing should be used as a construction quality control device during breaking to insure that a minimum elastic modulus is achieved before placing the AC overlay. However, research studies to assess the impact of such factors as slab size, crack spacing and subgrade support upon the NDT derived modulus need to be undertaken before implementation of this technique.

- The reduction in the structural capacity of the pavement after cracking and seating is approximately 25 to 30 percent. Or, the condition factor for converting cracked and seated PCC into an equivalent thickness of sound PCC is Cb = 0.75 to 0.70. This value has good agreement with the FAA's condition factor of Cb = 0.75 for slabs containing multiple cracking. The condition factor for converting cracked and seated PCC into an equivalent thickness of sound AC is Cb = 1.20 to 1.30.

- The conversion factors noted above are based on an average elastic modulus of 1920 ksi for the cracked and seated PCC. This value, as previously noted, is higher than the AASHTO recommended range of 500 to 1000 ksi. If the recommended range of values is used, the corresponding conversion factors are 0.5 to 0.6 for PCC and 0.8 to 1.0 for AC equivalent thicknesses.

- While the strength (hence structural capacity) of the PCC layer is significantly reduced after cracking and seating, the layer appears to behave as a semi-rigid material.

- Based upon the overall results of the study, the use of a modified FAA flexible pavement procedure for the design of AC overlays was recommended as an interim procedure.

Finally, it is important to note that this study by itself did not provide sufficient data to develop a crack/seat and AC overlay design procedure for PCC airfield pavements. However, the results of this study, in combination with other efforts such as this one, could lead to the development of an accurate methodology.

RECOMMENDATIONS

While useful information resulted from this investigation, the study did not provide enough data to develop accurate design recommendations for asphaltic concrete overlays on cracked and seated PCC airfield pavements. However, additional efforts such as this could lead to the development of an accurate design procedure.

With this in mind, together with the results of this study, the following recommendations are made:

- If at all possible, similar case studies at other field airport sites should be performed. The objective of these studies would be the development of a database that, with time, could serve as the basis for quantitatively determining the influence of various factors (such as crack spacing, spacing/type/preparation of existing joints, strength of PCC, subgrade, environment, traffic, etc.) upon the performance of cracked and seated pavements.

- Because most crack and seat projects have been performed on rigid highway pavements, a search (literature, agencies, etc.) of all pertinent information available from these projects should be conducted. This information would, in turn, be used to augment the database on cracked and seated pavements. This search however, should not be limited to highways but should cover airfield pavements as well.

- Based on the assumption that enough information can be collected and input into the database, a detailed analysis should be undertaken to accurately assess the impact of the various parameter (such as crack spacing and environment) upon the performance of cracked and seated pavements. This analysis should not only define the most important factors but also the magnitude of the impact of these factors upon the performance of the pavement.

- A standardized procedure(s) for determining the structural capacity (i.e., effective thickness) of cracked and seated pavements based on nondestructive testing, destructive testing, visual condition distress surveys, or combinations of these pavement evaluation procedures, etc., needs to be developed. An example of such a procedure was presented in this report where the structural capacity of the cracked and seated PCC layer was calculated based upon the NDT predicted elastic modulus. This is a vital factor in the overlay determination.

- An interim AC overlay design procedure needs to be developed/selected. Obviously, this design procedure must quantitatively incorporate the structural capacity of the PCC layer (and other existing layers) as well as the major factors affecting the performance of cracked and seated pavements. Furthermore, a verification study of the procedure needs to be made over a period of time. Feedback from this verfication study would allow the FAA to fine tune the developed/selected procedure.

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